Top 10 R&D Efforts for Novel Energy Solutions in Aerospace

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FROST & SULLIVAN

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Executive Summary

Research Snapshot

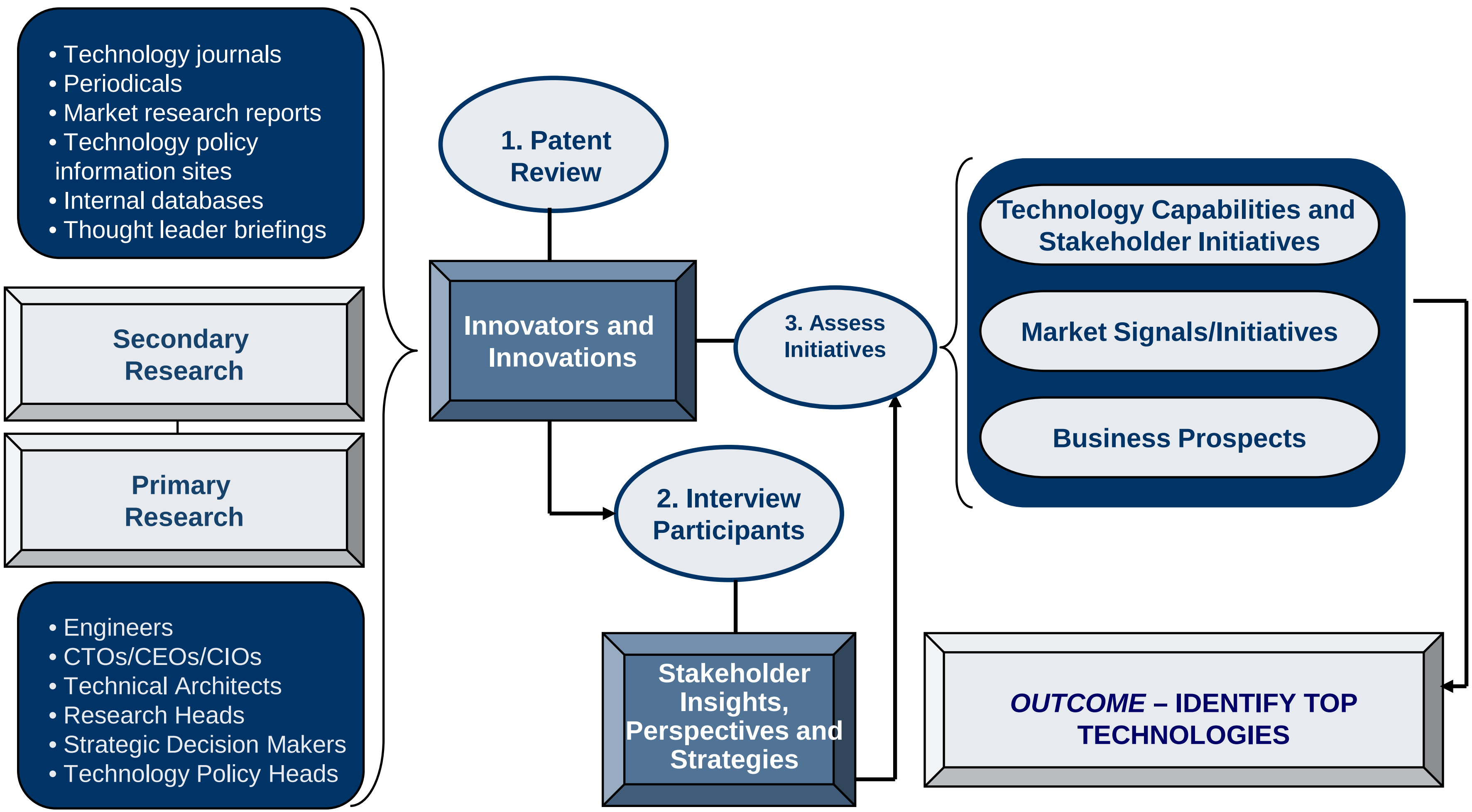
- The *Technical Insights* division of Frost & Sullivan has evaluated technology trends in novel energy solutions in aerospace and has identified 10 technology trends that are likely to have an impact in the aerospace energy domain.

- The top 10 technologies have been short-listed based on the number of aerospace energy themes that are being impacted while also considering the level of developments, and the challenges that the industry is facing today. These technologies are not ranked in any way.

- Information on each of the following aspects is provided lines on a best effort basis, as applicable to the technology under consideration:

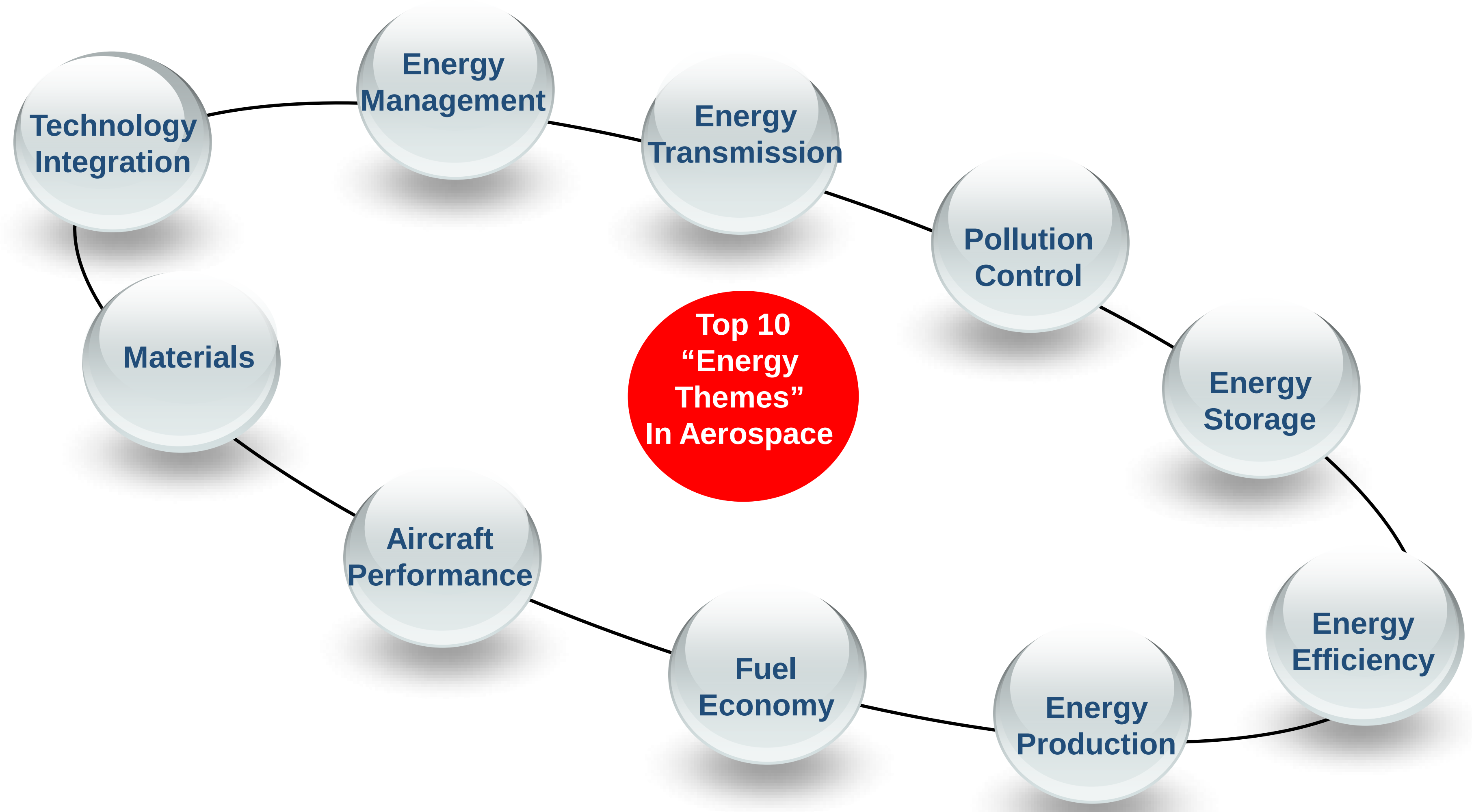
- Brief snapshot of the technology
- Key benefits or strengths
- Trends and initiatives
- Key stakeholders and their solutions
- Key drivers/challenges along with an expanded version in those cases where the listed driver/challenge is not self-explanatory
- Insights and recommendations

Research Methodology



Top 10 Themes in Aerospace Energy

Top 10 Themes in Aerospace Energy



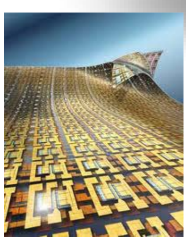
Source: Frost & Sullivan

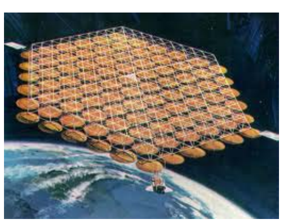
Top 10 Technologies

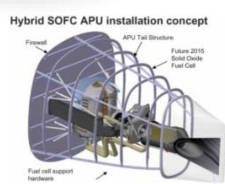
Top 10 R&D Efforts in Aerospace related to Energy

Top 10 R&D Efforts in Aerospace related to Energy

- Lightweight Printable Electronic Devices
- Novel Energy Solutions in Unmanned Aerial Vehicles (UAVs)
- Jet Biofuels
- Electric Aircraft
- Hybrid Aircraft
- Solar Aircraft
- Aircraft Terrestrial Taxiing System
- Fuel Cell as an Auxiliary Power Unit
- Space Solar Power System
- Aircraft On-Board Energy Storage







Source: Frost & Sullivan

I. Jet Biofuels

Jet Biofuels – Definition and Rationale

Tech Definition	Jet biofuels are algae- or cellulosic-based fuels that can replace currently used fossil-fuels-based jet petroleum in the aviation and aerospace industry.
Pertinent Themes	• Greenhouse gas (GHG) emission • Fuel cost • Fluctuating fuel prices • Energy production
Importance	Jet biofuels have potential for significant limitation in GHG emission by aircraft as well as to stabilize fuel cost and dependency on foreign oil.

Technology Intelligence

Using jet biofuels will not require aircraft engine modifications, which helps in cost savings.

Jet biofuels can be produced from biomaterials such as cellulosic-based materials or algae.

Some companies are able to deliver jet biofuel with high enough combustion quality (cetane number) that ensures high energy density allowing for more mileage per gallon of biojet.

Jet biofuels production is safer and could be a lesser carbon dioxide (CO_2) generating process than the production of currently used jet fuel.

Key Drivers for Jet Biofuels Development

Potential for lower fuel cost

Jet fuel is more expensive than gasoline used in the land transportation sector and has reached a price of approximately $110 per battel. Hence, it is easier for biofuels to be cost competitive with jet fuel. However, further development in this sector is needed to allow jet biofuels to decrease the price per gallon to the level of currently used jet-A fuel.

More stable aircraft operation costs

Jet fuel is responsible for even more than 40% percent of airlines' operation costs. It means that airlines' costs are highly dependant on the price of jet fuel and can change even from day to day due to oil price fluctuation. Notably, Jet-A fuel is much more expensive than gasoline or diesel, which is used in cars.

Compatibility with existing technology

Jet biofuel has the same chemical content than conventional Jet-A fuel used in commercial aircraft. Hence, it can easily replace Jet-A without any risk of engine durability.

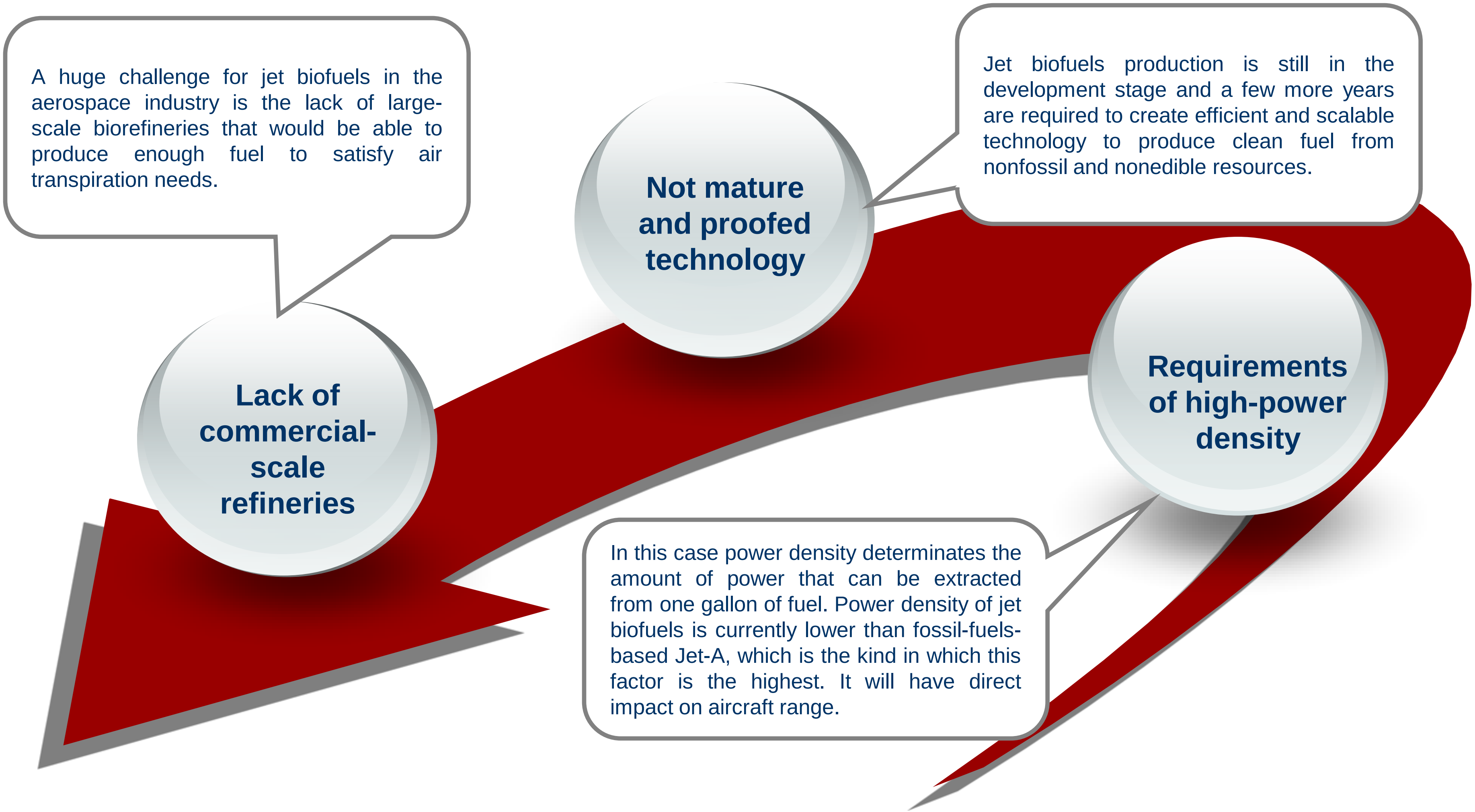
Lower GHG emission

Using biofuels in the aerospace industry could mitigate CO_2 emissions by 85%. More significantly, biofuels will ensure significant reduction in nitrogen oxide (NOx) emission when the aircraft is on the ground.

Lower dependency on foreign resources

Source: Frost & Sullivan

Key Challenges for Jet Biofuels Development



Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
NESTE OIL	Finland	The company develops its NExBTL technology to produce high cetane number (98) fuel, which can be used as jet fuel. The company has signed an agreement with Lufthansa to deliver high-power density clean renewable bio jet fuel to its airplanes. Lufthansa is planning to commence commercial flights using biofuels in the summer of 2011.
AMYRIS	USA	Amyris develops renewable jet fuel that can even outperform properties of currently used petroleum-based jet fuel due to the company's fuel performing well at low temperatures at high altitudes. Amyris is testing its renewable clean jet fuel in cooperation with such companies and institutions as US Air Force Laboratory, Southwest Research Institute, GE Aviation, Embraer and Azul Airlines. It plans to commercialize renewable jet fuel in the year 2014.
solazyme®	USA	The company is developing jet biofuels made from algae biomass. It has created Solajet, an algal-based HRJ-5 jet fuel by an appropriate fermentation process with the help of technology delivered by Honeywell. Tests show that Solazyme's algae-based jet fuel fulfilling requirements of the US Air Force have the same standard as commercial petroleum-based jet fuel. In comparison to fossil fuels, Solajet provides an 85% improvement in GHG emissions.

Key Developments (Contd…)

Key Developers	Location	Description of Innovation
AltAir Fuels	USA	The company develops bio jet fuel made from camelina. AltAir Fuels set an agreement with 14 airlines to deliver 750 million gallons of jet biofuels and biodiesel made from camelina feedstock.
SOLENA FUELS	USA	The company has plans to build the first refinery in Europe to produce jet biofuel from organic waste materials. Solena has collaborated with British Airways in this domain and the plant is expected to be ready in the year 2014. The production capacity is estimated for 16 million gallons of fuel production per year and all of this will be sold to British Airways.

Other Developers	Location
Arizona State University Laboratory for Algae Research & Biotechnology	USA
Energy & Environmental Research Center (EERC), University of North Dakota	USA
Cranfield University	UK
Washington State University	USA
Baylor University	USA
University of Dayton	USA

Analyst Insights

Despite the fact that jet biofuel has the same chemical composition as petroleum-based jet fuel, the biggest aircraft manufacturing companies (Boeing and Airbus) are conducting tests to ensure that their airplanes will be capable to run on the bio-jet without any inconvenience to engine performance or durability.

Commercial airlines are the most interesting bodies regarding developments in jet biofuels. Switching to biofuels could ensure them stability of fuel price, significant reduction in GHG emissions, or even better performance on certain circumstances (low temperature). Lowering in GHG emissions is specially important in Europe where airlines and airports need to fulfill requirements on GHG emissions imposed on them by the European Union. Such a requirement is not yet set in the United States, but it is expected to happen in the near future.

Commercial airlines are the most interested parties, but are not the only one either. Governments of two of the world's fastest developing countries China and the United States, are investing heavily into research on alternatives to petroleum-based jet fuel. Pentagon recently announced that it is very close to production of a jet biofuel based on algae biomass at the same cost as petroleum-based jet fuel that is currently in use.

Forming a jet biofuels alliances could help in accelerating the development of alternatives to conventional petroleum-based jet fuel. A good example of such an alliance is Brazilian Alliance for Aviation Biofuels (Aliança Brasileira para Biocombustíveis de Aviação – ABRABA). Its associate companies such as Algae Biotechnology, Amyris Brazil, the Brazilian Association of Jatropha Producers (Associação Brasileira dos Produtores de Pinhão Manso – ABPPM), the Brazilian Aerospace Industry Association (Associação das Indústrias Aeroespaciais do Brasil – AIAB), Azul Brazilian Airlines, Embraer, GOL Airlines, TAM Airlines, TRIP Airlines, and the Brazilian Sugarcane Industry Association (União da Indústria da Cana-de-Açúcar – UNICA). ABRABA is expected that other companies will also join the group to further accelerate technology development and scaling up.

Jet Biofuels can be usually used without any aircraft engine modification.

Jet biofuels can be used today for replacement of Jet-A fuel, and in future, in parallel to the other technology solutions allowing for more efficient and cleaner aircraft utilization.

II. Electric Aircraft

Source: Yuneec International

Electric Aircraft – Definition and Rationale

Tech Definition

Electric aircraft is a vehicle on which the jet engine and fuel tank have been replaced by an electric engine and battery pack. Energy to the battery pack is delivered from external sources by recharging it.

Pertinent Themes

- Aircraft Range
- Aircraft Speed
- Aircraft Pollution Limitation
- Aircraft Weight
- Aircraft Size
- Energy Storage
- Energy Management

Importance

Electric aircraft could be one of the solutions for the limited use of crude-oil-based jet fuel in the aerospace transportation sector. In addition, a significant cut down in aerospace sector GHG emissions can be achieved by introducing this technology.

Electric aircraft is quite a new concept that is developing on the small scale. Currently, a few small existing research projects are focusing on one or two sites for short-range aircraft.

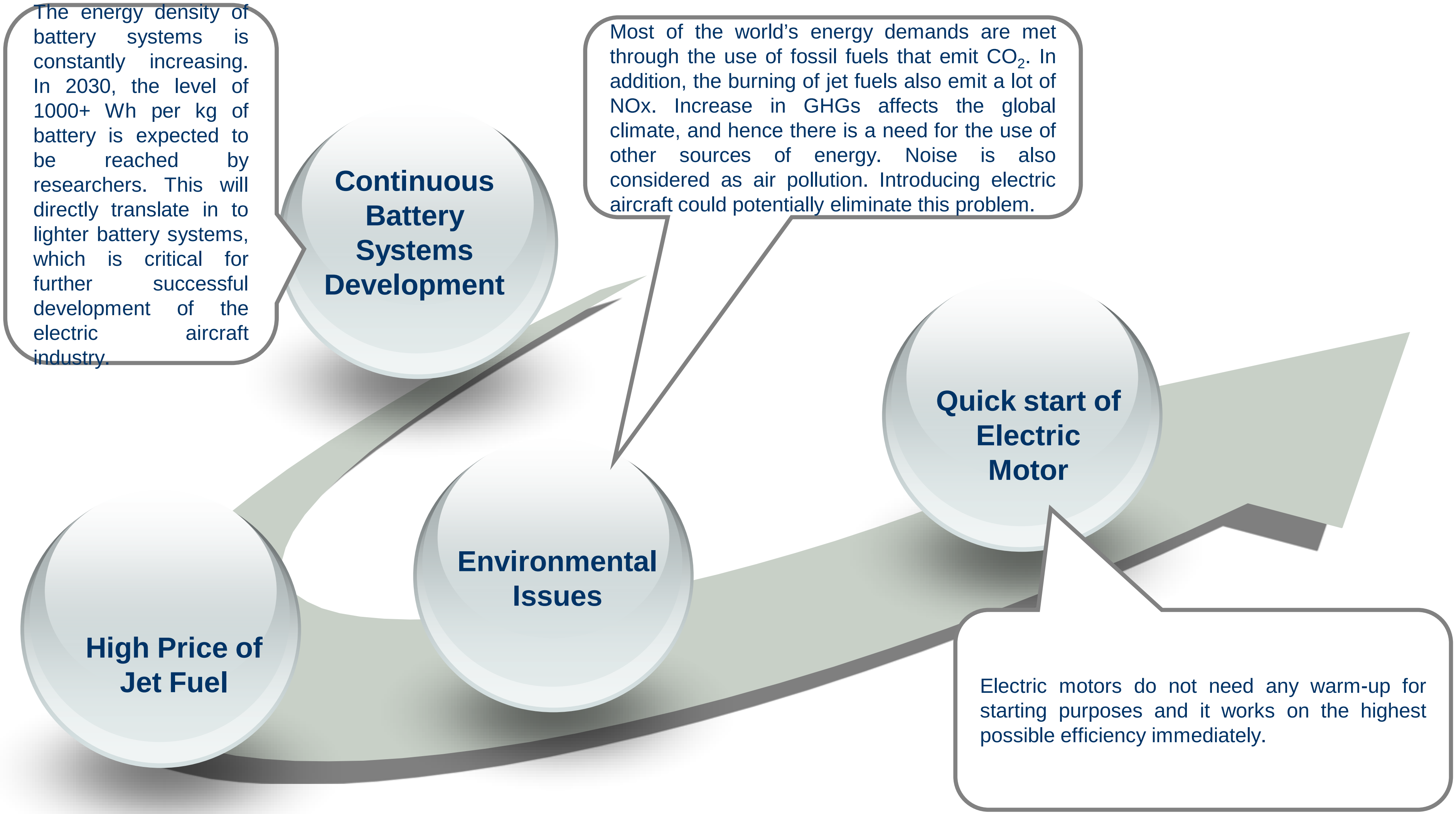
Developments in electric aircraft could help in limiting jet fuel usage in the aviation industry.

Replacing currently used combustion engines with electrical engines and battery systems could strongly reduce GHG emissions in the aerospace industry, especially NO_x, which is much more polluted and dangerous for human health than CO_2.

Aircraft electrification will significantly decrease the noise emission of airplanes.

Electric planes need shorter time (and distance) for take off.

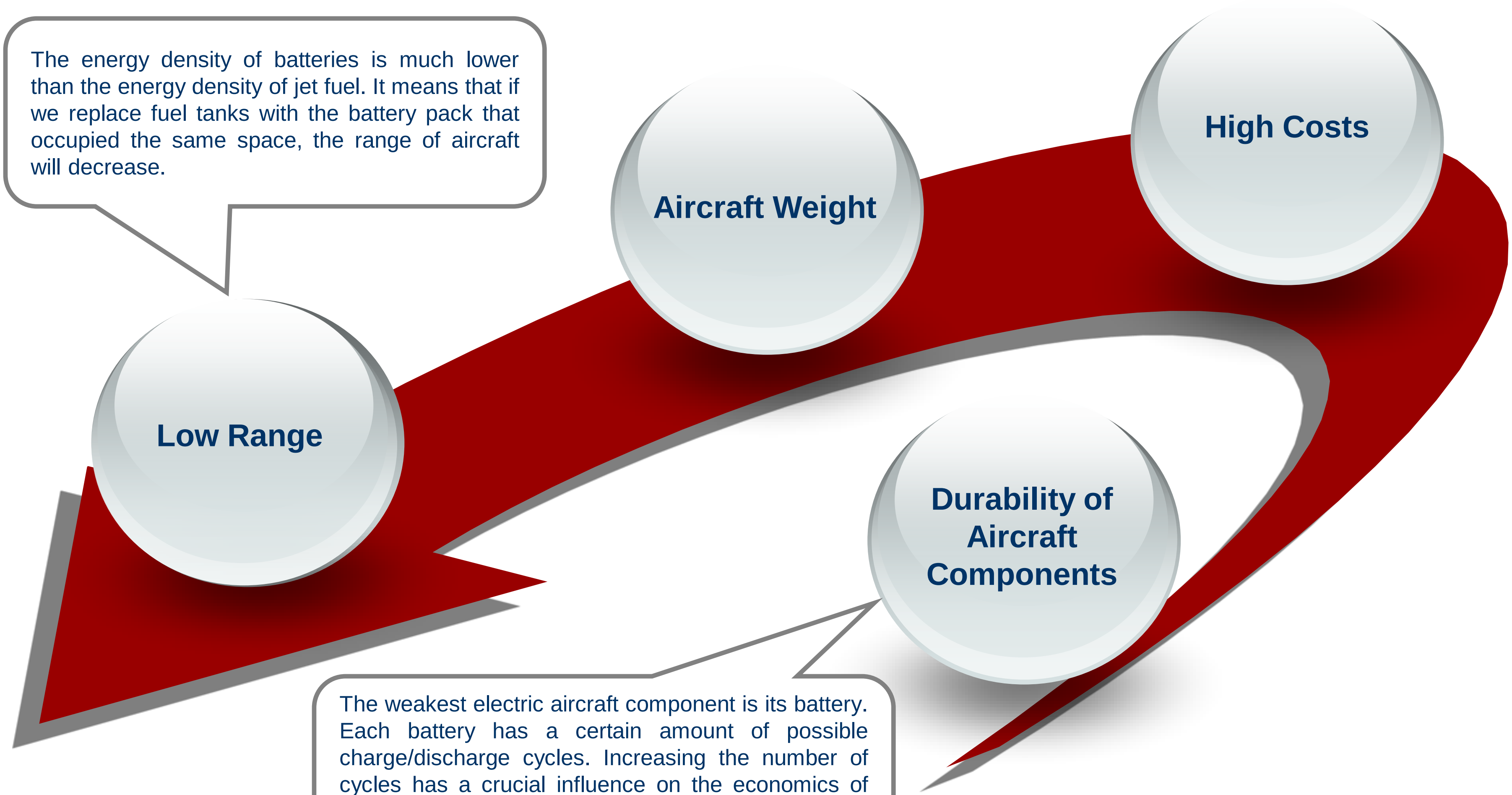
Key Drivers



Source: Frost & Sullivan

Key Challenges

The energy density of batteries is much lower than the energy density of jet fuel. It means that if we replace fuel tanks with the battery pack that occupied the same space, the range of aircraft will decrease.



The weakest electric aircraft component is its battery. Each battery has a certain amount of possible charge/discharge cycles. Increasing the number of cycles has a crucial influence on the economics of electric aircraft, since the battery pack is the plane's most expensive component.

Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
ELECTRAVIA, RAND-KAR	France	Electravia is developing its product Electra, which is the first fully electric plane in the world. Currently, the company is trying to enter the market with its new product, a motoglider Alatus-ME, which is distributed by the company Rand-Kar. Electravia delivers electric motors for the machine. Alatus-ME can stay in the air at least one hour in unsatisfactory weather conditions (for example, wind that will make gliding more difficult).
EADS, AERO COMPOSITES SAINTONGE	Germany, France	EADS Innovation Work (Germany) in cooperation with Aero Composites Saintonge is developing an electric plane called The Green Cri. It has a wingspan of 16 feet and the whole plane is 12 feet, 10 inches long, and 4 feet high. It is a single-person plane equipped with low-intensity brushless electric motors with counter-rotating propellers. Four packs of lithium-polymer batteries (5Ah) allows for 0.5 hour flight at a speed of 110 kph. The total plane weight with a pilot is 175.5 kg. The Green Cri will hold its first flight in the near future.
YUNEEC INTERNATIONAL	China	Yuneec international has developed the first commercially available fully electric plane. The company's product is called E430 Electric Aircraft and it's a two-seat fully electric sport aircraft. E430 used a lithium-polymer battery that allows for a 2 hour flight and has a lifetime of 1500 charging-discharging cycles, which gives 3000 hours of flight. Standard battery charging will take approximately 3 hours. However, Yuneec is working on a fast charging station that will allow for charging the battery in one hour's time.

Key Developments (Contd…)

Key Developers	Location	Description of Innovation
Sikorsky A United Technologies Company iPower Systems US Hybrid Eagle Technologies, LLC	USA	Firefly is an electric helicopter build by Sikorsky and partner companies. Helicopters use a 150 kW electric engine delivered by US Hybrid and two lithium-ion batteries packages of 45 Ah capacity delivered by iPower. Eagle Technologies will perform unit modification. The technology demonstration helicopter will be able to stay in the air for 15 minutes with one pilot inside.
Bye Energy	USA	The company is developing a fully electric plane in cooperation (among others) with Cessna for replacing conventional combustion engines with electric engines and battery packs that could allow for 4 hours of flight for one of the most popular airplanes, the Cessna 172.

Other Developers

Other Developers	Location
Cranfield University	UK
University of Cambridge	UK
NASA	USA
University of Stuttgart	Germany
Stanford University	USA
Sonex	USA
Electric Aircraft Corporation	USA
PC-Aero	Germany

Analyst Insights

Fully electric aircraft are in early development stages and challenges of battery lifetime, aircraft weight and range need to be overcome before this technology could be considered safe and cost competitive with currently used aircraft powered by standard engines.

Aircraft that is fully electric is considered only for small vehicles that will be able to carry one to four people. The energy density of currently available electric storage systems is too small to think about using this technology in large aircraft such as Boeing or Airbus.

Further developments could allow for a decrease in manufacturing and component cost and weight. Hence, clean and quiet electric small aircraft has the potential to replace today's most popular recreation--the small airplane CESNA-172.

Development of electric airplanes depends partly on the development of electric cars, especially in the field of batteries. Everything that will find good application in an electric car will also be considered useful for the electric airplane industry.

The next generation of propeller airplanes is expected to rely on electric engines.

Electric airplanes are still in the development stage with the potential for using small recreation machines in 10 years time.

III. Solar Aircraft

Source: Bye Energy

Solar Aircraft – Definition and Rationale

Tech Definition	Solar aircraft is a vehicle on which jet engines and fuel tanks have been replaced by electric engines and battery packs. Energy to the battery pack and to the engine is supplied by the solar panels attached to the airplane's wings.
Pertinent Themes	• Aircraft Range • Aircraft Speed • Aircraft Pollution Limitation • Aircraft Weight • Aircraft Size • Energy Storage • Energy Management • Solar Panels Integration
Importance	Solar aircraft could be one of the solutions for the limited use of crude-oil-based jet fuel in the aerospace transportation sector. In addition, a significant cut down in aerospace sector GHG emissions can be achieved by introducing this technology.

Technology Intelligence

Solar aircraft is quite a new concept that is developing on a small scale. Currently, a few small existing research projects are focusing on one or two sites for the aircraft.

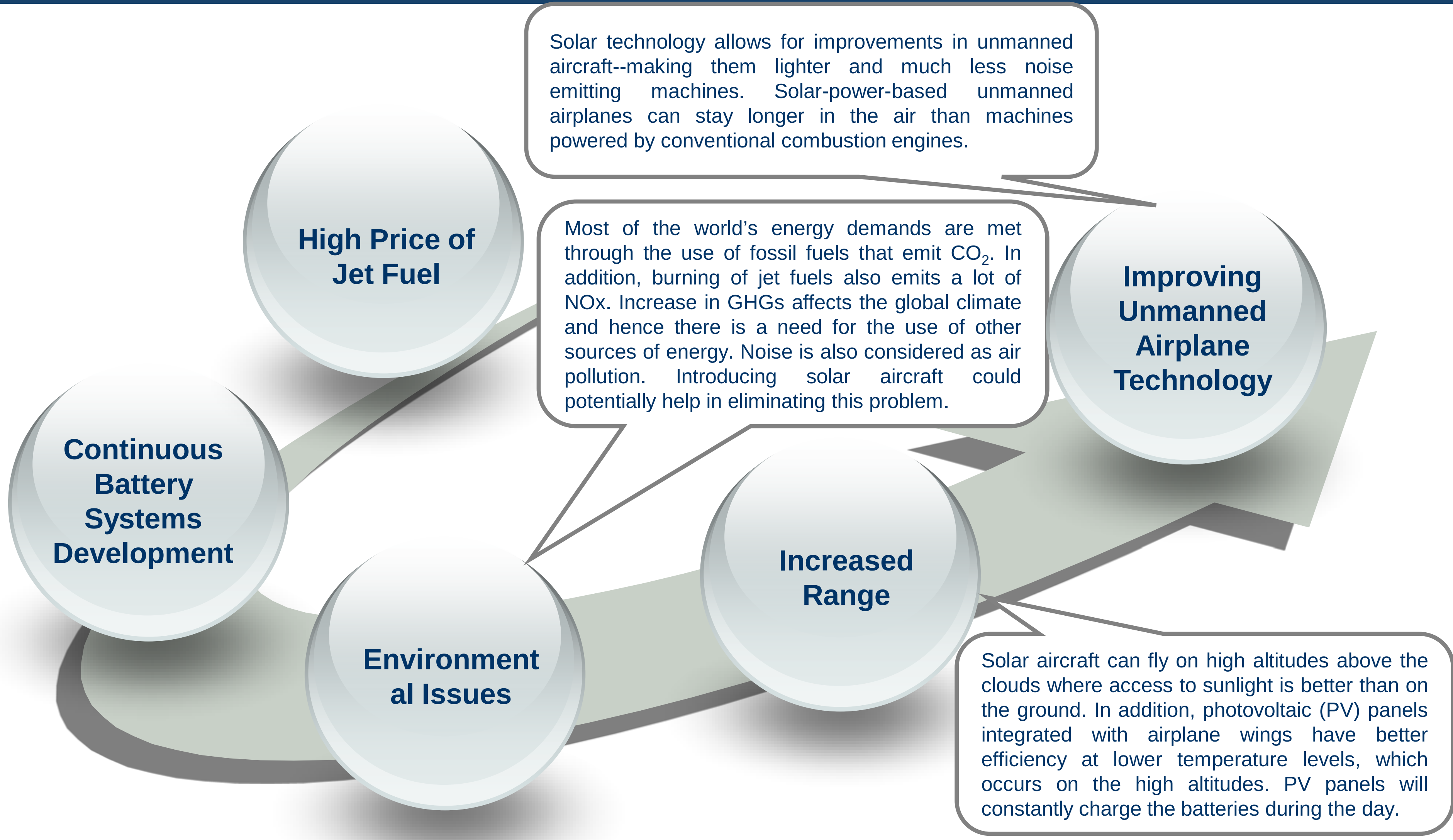
Developments in solar aircraft could help in limiting jet fuel usage in the aviation industry.

Replacing currently used combustion engines with electrical engines and battery systems could strongly reduce GHG emissions in the aerospace industry, especially NO_x, which is much more polluted and dangerous to human health than CO_2.

Using solar energy in aircraft will significantly decrease the noise emission of airplanes.

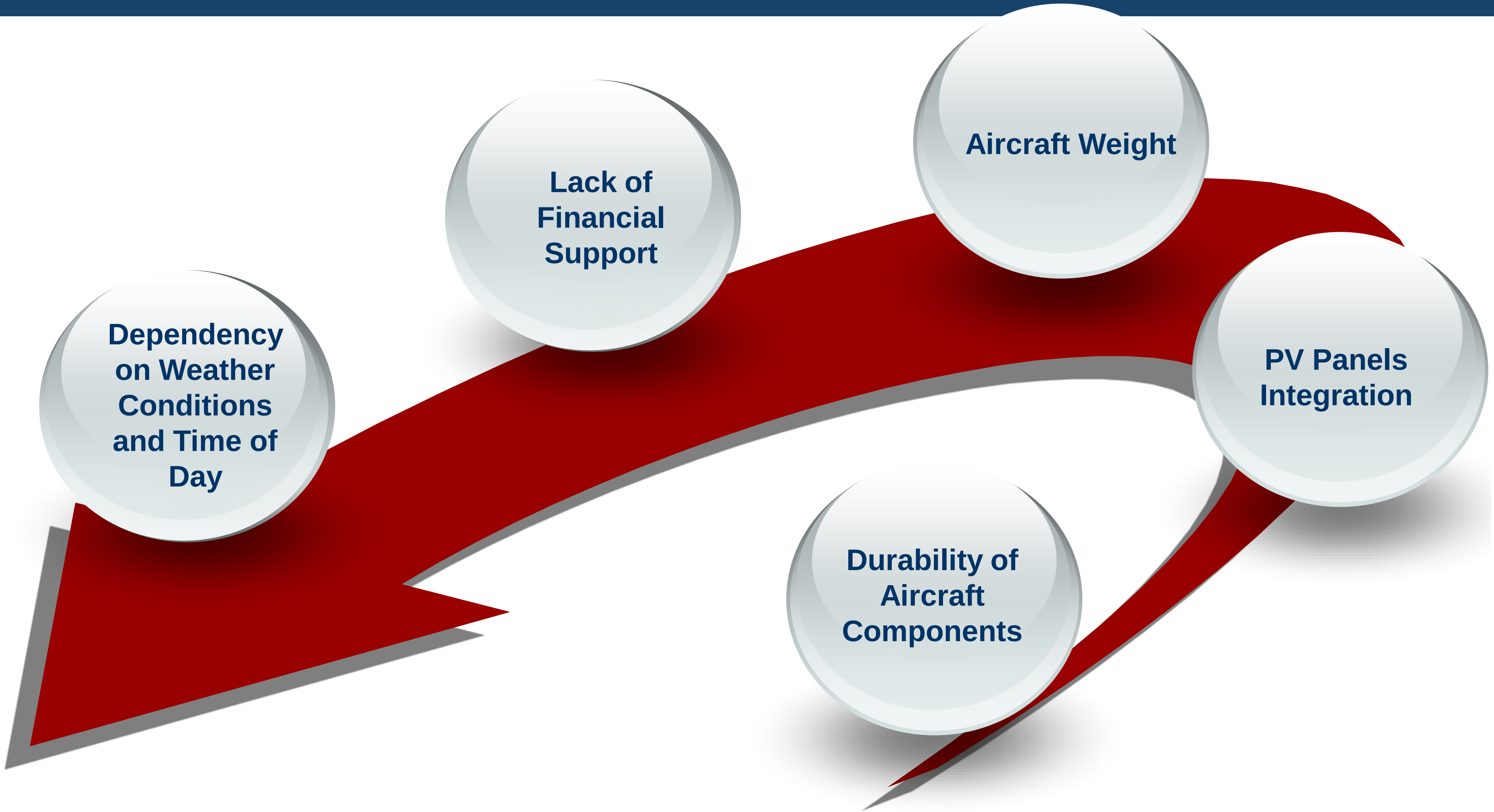
Solar planes could have more range than electric aircraft due to access to the energy source (sunlight) while flying.

Key Drivers



Source: Frost & Sullivan

Key Challenges



Challenges described on the next slide

Source: Frost & Sullivan

Key Challenges (Contd…)

Dependency on Weather Conditions and Time of Day

Despite the fact that an electric airplane can fly above the clouds it is still dependant on the availability of sunlight. Because of this fact, solar airplanes can not be used during night time. Some models are provided with battery packs that allow for safe landing on the ground.

Lack of Financial Support

Governments and major research institutions such as NASA are not supporting the development of solar-powered planes, which has slowed down improvements in this domain.

Aircraft Weight

Compared to electric aircraft, solar airplanes have additional ballast in the form of integrated PV panels. Developments in the area of PV panels for solar aviation purposes is needed. Battery packs could be smaller than on electric aircraft since they are used mostly for compensating the intermittent character of electricity produced by PV panels.

PV Panels Integration

Developers are still looking to improve ways of integrating PV panels with airplane envelopes. It should be done in a way that will ensure good PV and wings durability, especially in the places of its junction.

Durability of Aircraft Components

The weakest solar plane components are the battery and PV panels. Batteries used in solar planes have a longer lifetime than those used in electric planes since they are not fully discharged during a flight since PV panels constantly deliver electricity to charge them. Batteries in solar planes work in a similar manner to the batteries in hybrid cars. It is constantly charged on an average of 80%.

Key Developments

Key Developers	Location	Description of Innovation
Bye Energy	USA	The company has a plan in the future for the integration of thin-film solar cells into its electric Cessna-172, which it develops together with Cessna A Textron Company.
SolarFlight	USA, Slovenia	The company is developing the Sunseeker II, which is a two-seater solar plane. It is looking for its first flight in the summer of 2011. The company's CEO Eric Raymond has over 25 years of experience in research on integration of solar panels with aircraft. The company is using lithium-polymer batteries, but is considering changes in this technology for lithium-ion batteries due to safety issues. There is a risk of fire in lithium-polymer batteries. The company is using SunPower's monocrystalline silicon solar cells.
SOLARIMPULSE EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE	Switzerland	The company has built a single-person solar plane that can stay in the air for 26 hours of continued flight also through the night. The airplane is 21.8 m long, 6.4 m high, and has a 63.4 m wingspan (the same as Airbus A340) and its weight is 1600 kg. The plane's propulsion is delivered by four 10 HP electric engines. The on-board electricity storage system is provided by the batteries that have energy density of 240 Wh/kg and a total weight of 400 kg. Energy to the batteries is provided by 12,000 solar panels integrated with plain wings and horizontal stabilizers. Solar panels charge batteries for a day (also during a flight) and then this energy is used to power the airplane at night. Solar Impulse is expected to perform flights around the world in the year 2013/2014. This company has been developed in cooperation École Polytechnique Fédérale de Lausanne (EPFL).

Key Developments (Contd…)

Key Developers	Location	Description of Innovation
QinetiQ	UK	The company has developed a Zephyr solar plane, which is a UAV that proved its performance in over 14 days of continuous flight.

Other Developers	Location
Cranfield University	UK
University of Cambridge	UK
NASA	USA
University of Stuttgart	Germany
Stanford University	USA
Sonex	USA
Electric Aircraft Corporation	USA
PC-Aero	Germany

Analyst Insights

Solar airplanes are capable to fly on high altitudes where solar radiation is more available than on the ground.

Solar panels gain efficiency when the temperature of the environment goes down. It means the higher the altitude of the plane's flight, the better the PV panels' efficiency due to lower ambient temperature. In some cases, solar planes can even perform better on high altitudes than planes that use gasoline engines due to lack of oxygen needed for proper fuel combustion.

There are only a few projects developing the concept of solar airplanes due to a lack of funding possibilities.

The most important aspect for further development of solar airplanes is improvement in the power densities of batteries. Currently available batteries are still too heavy.

Currently, the biggest potential for the use of solar power in airplanes is in the UAV industry. UAVs are used today by the defense sector and are mostly powered by gasoline engines. Switching to solar power in this case can allow for much longer time in the air without landing and refilling fuel. In addition, such an airplane that produces no pollution and is completely silent is very important for the defense industry.

Solar planes can have a much larger range than electric or even gasoline engine planes, but development in on-board energy storage systems is still needed.

IV. Hybrid Aircraft

Hybrid Aircraft – Definition and Rationale

Tech Definition	Hybrid aircraft is an electric aircraft with an additional lightweight combustion engine.
Pertinent Themes	• Aircraft Range • Aircraft Speed • Aircraft Pollution Limitation • Aircraft Weight • Aircraft Size • Energy Storage • Energy Management
Importance	Hybrids planes are aiming to be a transition technology between gasoline engine planes and fully electric planes.

Technology Intelligence

Hybrid propulsion systems could significantly increase the range and reliability of the electric plane.

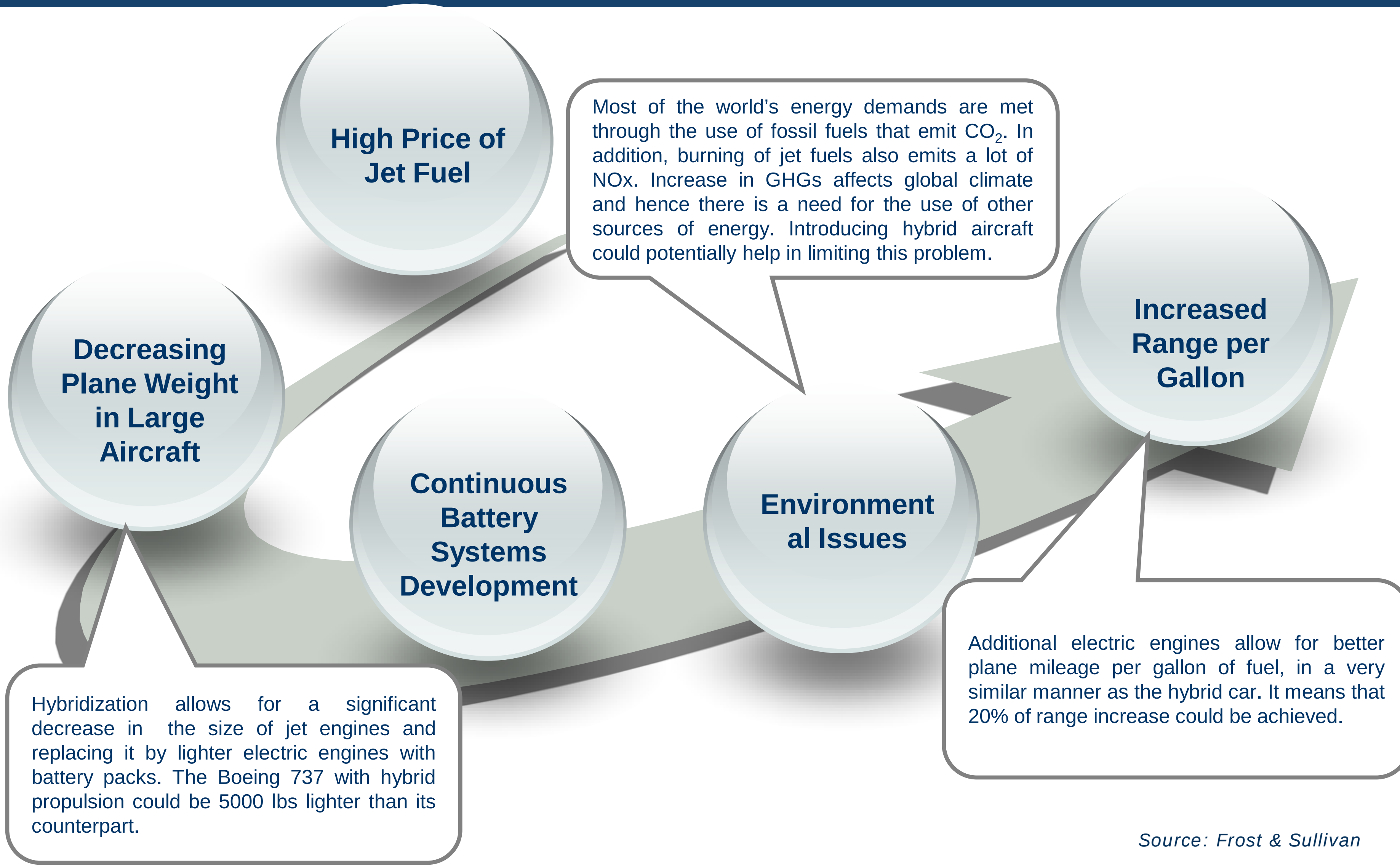
Hybrid planes are aiming to be the same for the aerospace industry as hybrid cars are for the automotive industry.

Light high-power density combustion engines are available today.

All elements needed for building a hybrid plane are available today. However, it needs proper and optimal joining on the board of the aircraft.

The hybridization of planes have the potential for to increase the range of existing planes and decrease GHG emissions at the same time.

Key Drivers



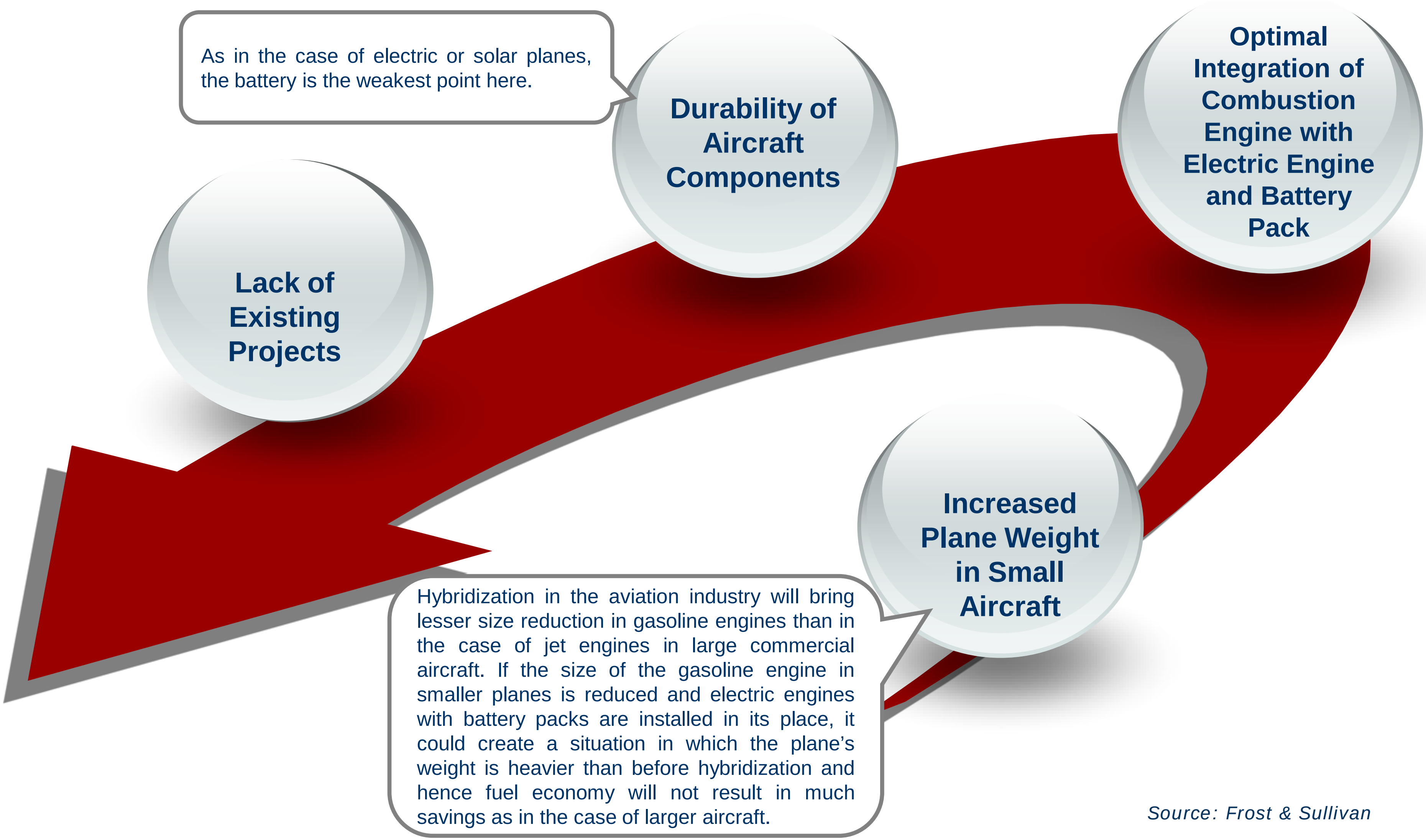
Most of the world's energy demands are met through the use of fossil fuels that emit CO_2. In addition, burning of jet fuels also emits a lot of NOx. Increase in GHGs affects global climate and hence there is a need for the use of other sources of energy. Introducing hybrid aircraft could potentially help in limiting this problem.

Hybridization allows for a significant decrease in the size of jet engines and replacing it by lighter electric engines with battery packs. The Boeing 737 with hybrid propulsion could be 5000 lbs lighter than its counterpart.

Additional electric engines allow for better plane mileage per gallon of fuel, in a very similar manner as the hybrid car. It means that 20% of range increase could be achieved.

Source: Frost & Sullivan

Key Challenges



Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
	USA	NASA began work on hybrid airplanes in 2008. The researchers modified an existing electric plane and added a compact combustion engine to increase its range. It was a small one- to two-seater plane with a range of 720 miles and a fuel economy of 100 mpg. Other advantages of this plane are shorter take-off time/distance and the possibility of achieving higher altitudes.
	USA	The company is working on a concept for a hybrid plane called SUGAR Volt. SUGAR means subsonic ultragreen aircraft research. The plane is similar in size to the Boeing 737 and is equipped with two engines and a hybrid partly electric propulsion system. The plane used 70% less fuel and 55% less energy overall. It could run on biofuel as well, which will further decrease its GHG emission. It can carry 154 passengers and has a range of 3500 miles. However, the goal is to fly average distances of 900 miles while in such cases the plane mostly uses energy from the battery rather than fuel. Longer flights means lower fuel economy and more gallons per mile will be burned.

Other Developers	Location
Hybrid Aircraft Corporation	USA
Lockheed Martin	USA

Analyst Insights

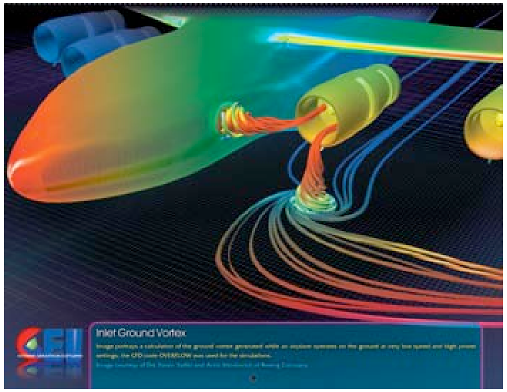
Aircraft hybridization could be a good idea for larger machines rather than for small ones. However, the first commercial large aircraft is expected to be ready for testing much earlier than 2030.

Next Generation Air Traffic Control can significantly improve the performance of hybrid (and not only) aircraft flight. With this system, more direct flight will be possible due to good communication and ensuring the possibility of continuous climb and descent of the aircraft. These two maneuvers are responsible for the maximum fuel consumption by the plane, just like in the case of an accelerating car.

Hybridization can bring in the advantage of lightweight planes for larger aircraft rather than for small ones due to size and power of engines. In addition, Jet-A fuel is more expensive than gasoline used in the smaller plane aviation industry. Hence, hybridization of larger aircraft is more economically viable.

Hybridization can provide advantages in larger airplanes, but commercially available hybrid aircraft is not expected for another 20 years.

V. Aircraft Terrestrial Taxing System



Source: Wheel Tug

Aircraft Terrestrial Taxiing System – Definition and Rationale

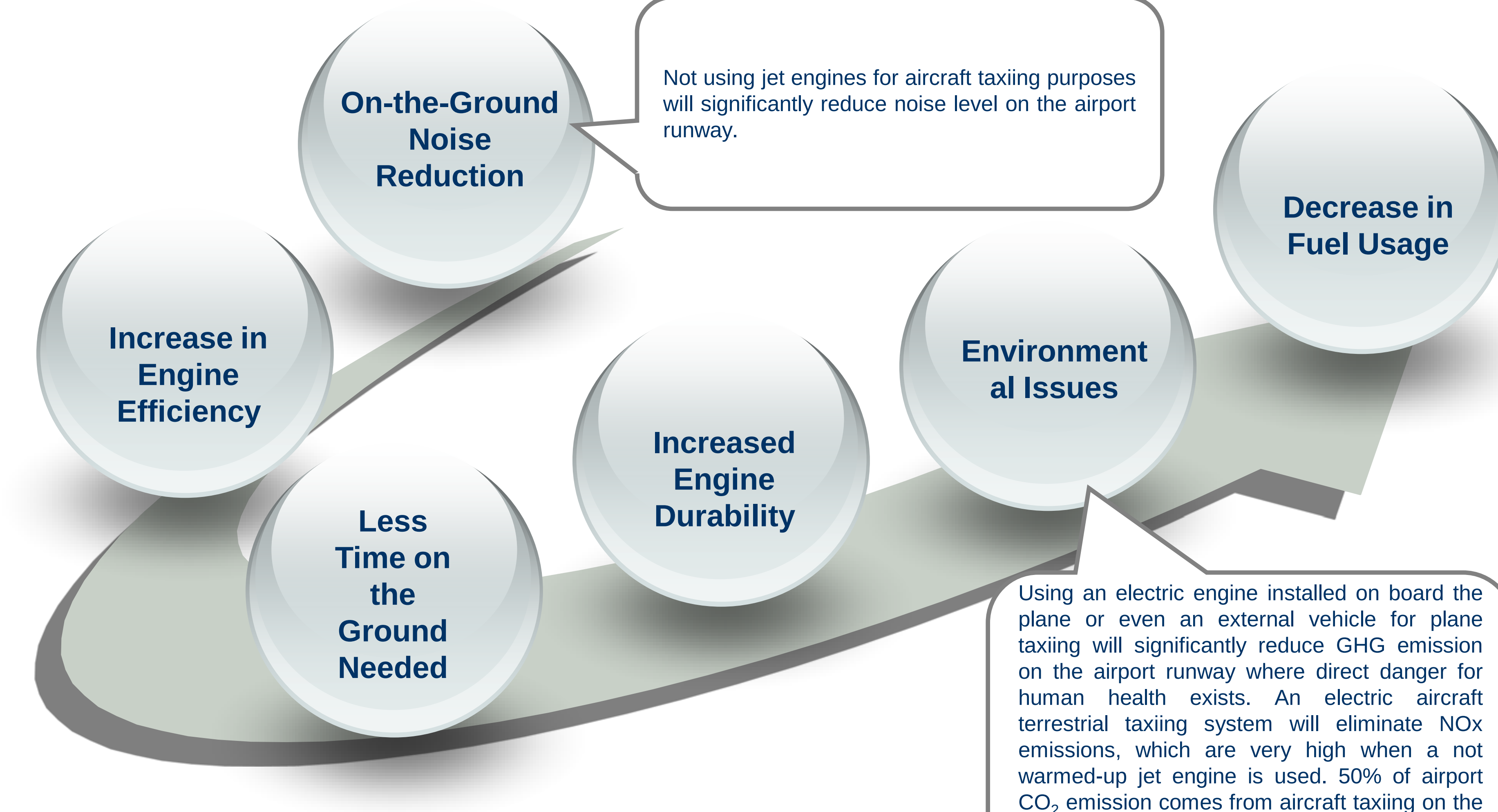
Tech Definition	Taxiing system is used for a moving plane while on the ground.
Pertinent Themes	• Aircraft Range • Engine Efficiency • Aircraft Pollution Limitation • Fuel Economy • Engine Durability
Importance	Airports all over the world are getting more serious about controlling GHG emission (especially in Europe). Aircraft emitting the highest amounts of GHG (especially NOx, which is much more polluted and dangerous for human health than CO_2) during taxiing on airports when engines are not warmed up.

The idea of a novel aircraft terrestrial taxiing system is in not using plane engines for taxiing and plane movement while on the ground.

One of the solutions in this case can be the use of electric motors that will fly together with the plane and will be used for taxiing proposes while the plane is on the ground. An electric motor could be attached to or fit into the aircraft wheel. In this case an additional source of energy is required when the engine is not working (for example, batteries) or in some cases the plane's auxiliary power unit (APU) could deliver enough power for such systems.

The other possible solution is a special taxiing vehicle that could be used for a moving plane on the airport runway without the necessity of starting its engine.

Key Drivers



Not using jet engines for aircraft taxiing purposes will significantly reduce noise level on the airport runway.

Using an electric engine installed on board the plane or even an external vehicle for plane taxiing will significantly reduce GHG emission on the airport runway where direct danger for human health exists. An electric aircraft terrestrial taxiing system will eliminate NOx emissions, which are very high when a not warmed-up jet engine is used. 50% of airport CO_2 emission comes from aircraft taxiing on the runway (including people driving in and out of the airport in their cars).

Drivers described on the next slide

Source: Frost & Sullivan

Key Drivers (Contd…)

Increase Engine Efficiency

Working jet engines are “eating” dirt and other garbage while on the ground. This effect is caused by the vortex air spinning phenomena. Dirt, rocks and other garbage are damaging to engine blades and cause cracks on the edges. These cracks are usually removed by grinding, which changes the shape of the blades and makes them less efficient. Enabling plane taxiing without the necessity of starting the engine while the aircraft is on the ground will eliminate this problem.

Increase Engine Durability

Less cracks on engine blades will also increase engine durability and reliability by preventing its elements from damage.

Decrease in Fuel Usage

If the engine is not necessary for plane taxiing purposes then significant reduction on fuel usage can be achieved while the plane is on the ground. In addition, due to increased engine efficiency over the timeframe (described above), the plane will have better fuel economy not only while on the ground, but also during flight.

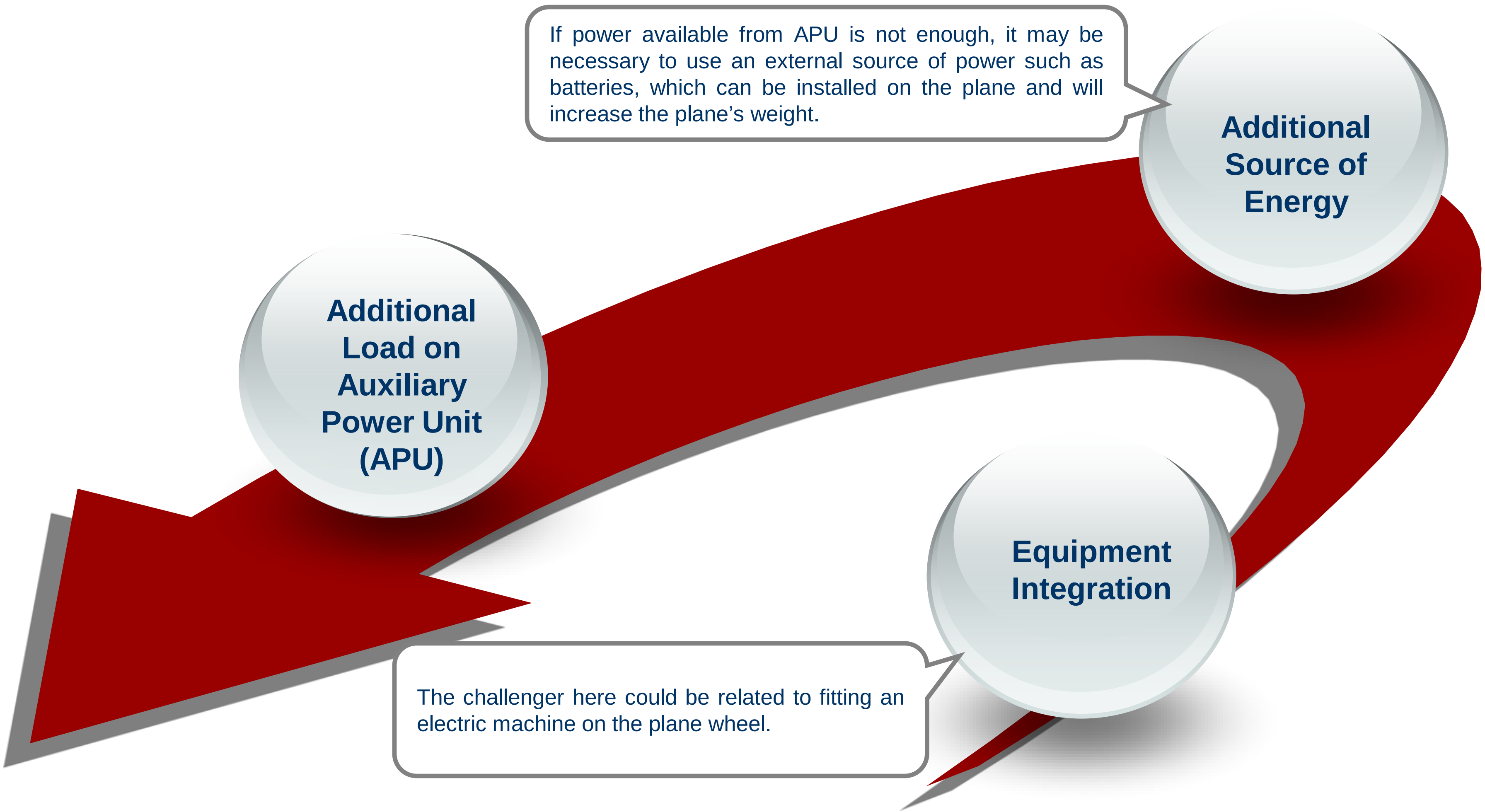
Less Time on the Ground Needed

Electric engines installed on board an airplane is ready to be operated immediately and does not need warming up like jet engines for providing power to taxi the aircraft. It means that the plane can spend less time on the ground, which will result in shorter connection times and more revenues for airlines.

Less Time on the Ground Needed

Compared to electric aircraft, solar planes have additional ballast in the form of integrated PV panels. Developments in the area of PV panels for solar aviation purposes is needed. The battery pack could be smaller than on electric aircraft since it is used mostly for compensating the intermittent character of electricity produced by PV panels.

Key Challenges



Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
WheelTug® DRIVING AEROSPACE	UK	The company is developing an aircraft terrestrial taxiing system that eliminates the necessity of using main plane engines for taxiing purposes while the plane is on the ground. This technology uses only power available from the standard APU installed on board currently used aircraft. The technology is based on small electric engines installed into the aircraft wheel, which is able to move a plane as big as an Boeing 737 with the typical taxiing speed. The technology has been already tested and is expected to be commercially available in 2012.
DELOS AEROSPACE	USA	This company is also developing an aircraft taxiing system based on an electric motor installed into the plane wheel. However, in this case the electric motor is powered by the battery, which needs to be additionally installed on the airplane. Delos Aerospace technology allows for energy recovery when the plane brakes after landing. In such a case, the electric motor turns in to a generator and produces electricity, which is then stored in the batteries for plane taxiing purposes or other plane energy demands. In addition, during landing the plane's wheels can be prespun to match the ground speed, which will result in the elimination of sliding friction that has a negative influence on the tire wear. Additionally, it will eliminate the deposit of reverted rubber onto the runway, which reduces the available friction coefficient during braking in rainy weather.

Key Developments

Key Developers	Location	Description of Innovation
ISRAEL AEROSPACE INDUSTRIES (IAI)	Israel	The company has developed the TaxiBot system, which is a tractor that tows an airplane from the gates to the runway before starting and from the runway to the gate after landing, so the use of the main engine for taxiing purposes will be eliminated. TaxiBot is powered by two diesel engines and can be controlled by the pilot from the plane's cockpit using the same controls and movements that the pilot has been trained to use during full engine maneuvers. The biggest advantage of this solution is that no plane modification is required to make this system work. Researchers from IAI are planning to develop hybrid or even fully electric TaxiBots in the future.
SAFRAN Messier-Bugatti	France	The company is developing an electric taxiing system that will be installed on the main landing gears. Electric motors that will be used for movement of the aircraft will be powered by the plane's APU unit. This technology is expected to be ready for commercialization not earlier than 2016.

Analyst Insights

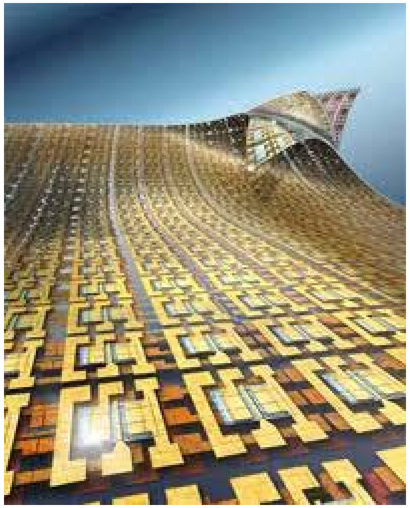
Electric aircraft terrestrial taxiing systems such as those developed by WheelTug or Safran can deliver technology that will ensure less airplane time on the ground, significant GHG reduction, and increase in engine efficiency over its lifetime.

Airbus estimates that fuel consumed by aircraft during taxiing on the ground will reach a cost of $7 billion by the year 2012. Using the main engines of the plane for moving from and to the gates of the airport is also responsible for 18 million tons of CO_2 emissions annually. An aircraft terrestrial taxiing system (ATTS) can significantly reduce these numbers. In addition, a jet engine acts like a big blower, which bears the risk of damage to nearby objects and devices. The cost of these damages is estimated at $350 million annually. This challenge will be eliminated with the use of an ATTS.

The system delivered by WheelTug allows for yearly savings of at least $500,000 per aircraft and will provide half of the value of re-engineering the airplane for much less cost. WheelTug makes older planes economically viable by upgrading them, thus enabling them to continue flying instead of buying new planes. The cost of this technology will be half of an airline's annual savings. The company can place its system for $100,000 of the marginal cost. This system will deliver monthly savings of $25000 to $30000, which has a payback time of a few months.

ATTS is a technology allowing for reduction of an aircraft's fuel usage and limitation in GHG emissions while increasing engine efficiency and will be available on a commercial scale next year.

VI. Lightweight Printable Electronic Devices



Lightweight Printable Electronic Devices – Definition and Rationale

Tech Definition	Lightweight printable electronic devices such as lighting systems, PV cells and elements for super capacitors are flexible light devices that can significantly reduce aircraft weight and bring more flexibility into usage of some its components.
Pertinent Themes	• Aircraft Weight • Engine Efficiency • Aircraft Pollution Limitation • Fuel Economy • System Integration
Importance	Flexibility, easy integration and light weight are the main factors determining suitability of technology for energy solutions in the aerospace industry.

Technology Intelligence

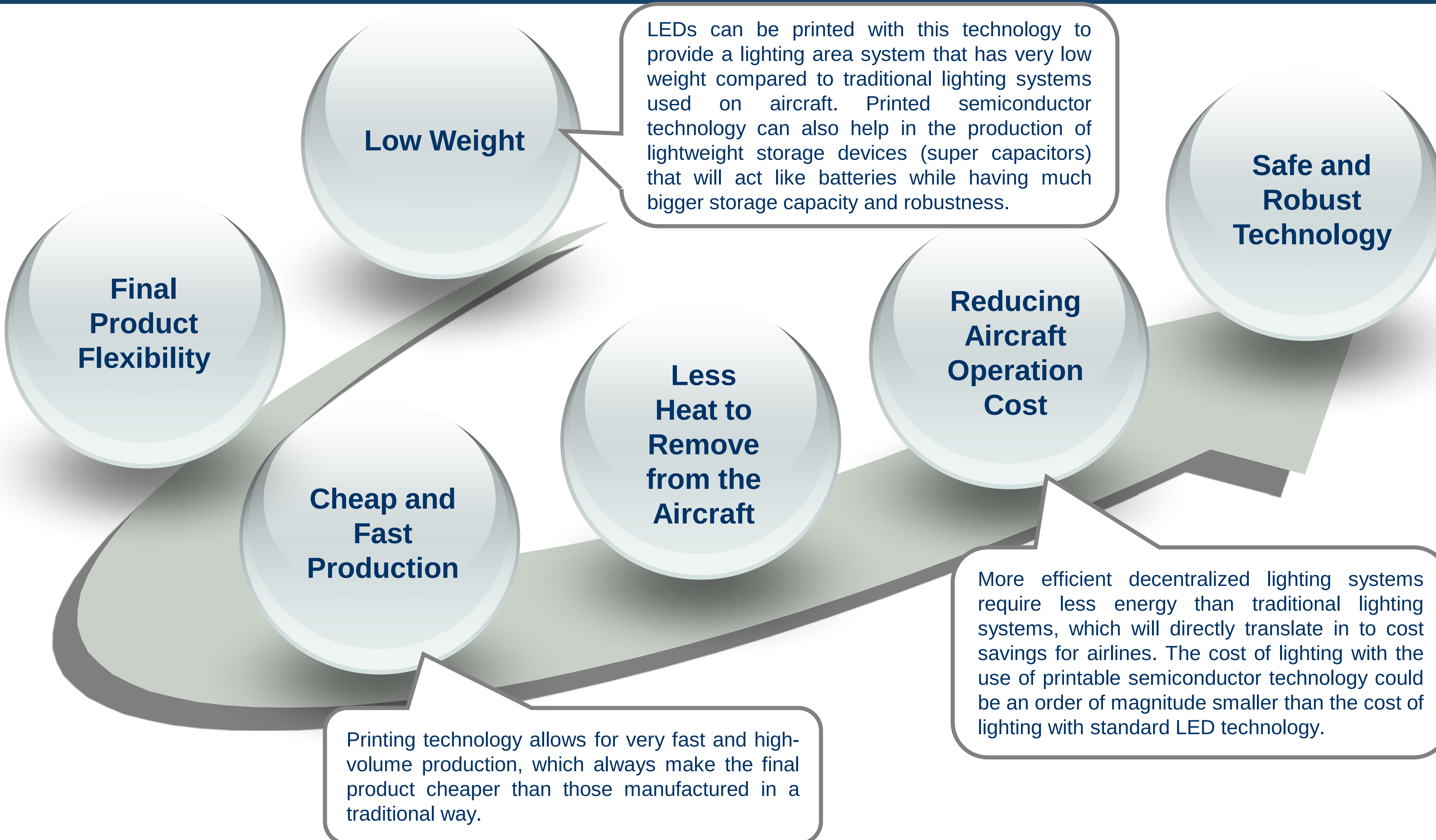
The technology is based on printable semiconductors that can be used in lighting and energy production and storage devices. With this technology, light emitting diodes (LEDs) as well as transistors can be printed on the area surface.

Low-energy low-mass lighting devices that can be printed by using this technology could be very important for the aerospace industry since decreasing energy demand and weight are always in the interest of aircraft manufacturers as well as space shuttle designers.

In terms of energy storage devices, this technology could help in creating super capacitors that act like a battery, but has much bigger capacity, robustness, and is lighter than a battery of the same capacity. The technology behind it uses single-walled carbon nanotubes (CNTs) and suspends them in ionic liquid, which acts like an electrolyte. Control of CNTs while in the ionic liquid is possible, hence during printing, CNTs can orient themselves into very dense vertical lines. This provides the large surface area that is needed to optimize charge storage capacity.

Light printable PV cells could find application in the space industry to be integrated with space shuttles.

Key Drivers



Source: Frost & Sullivan

Key Drivers (Contd…)

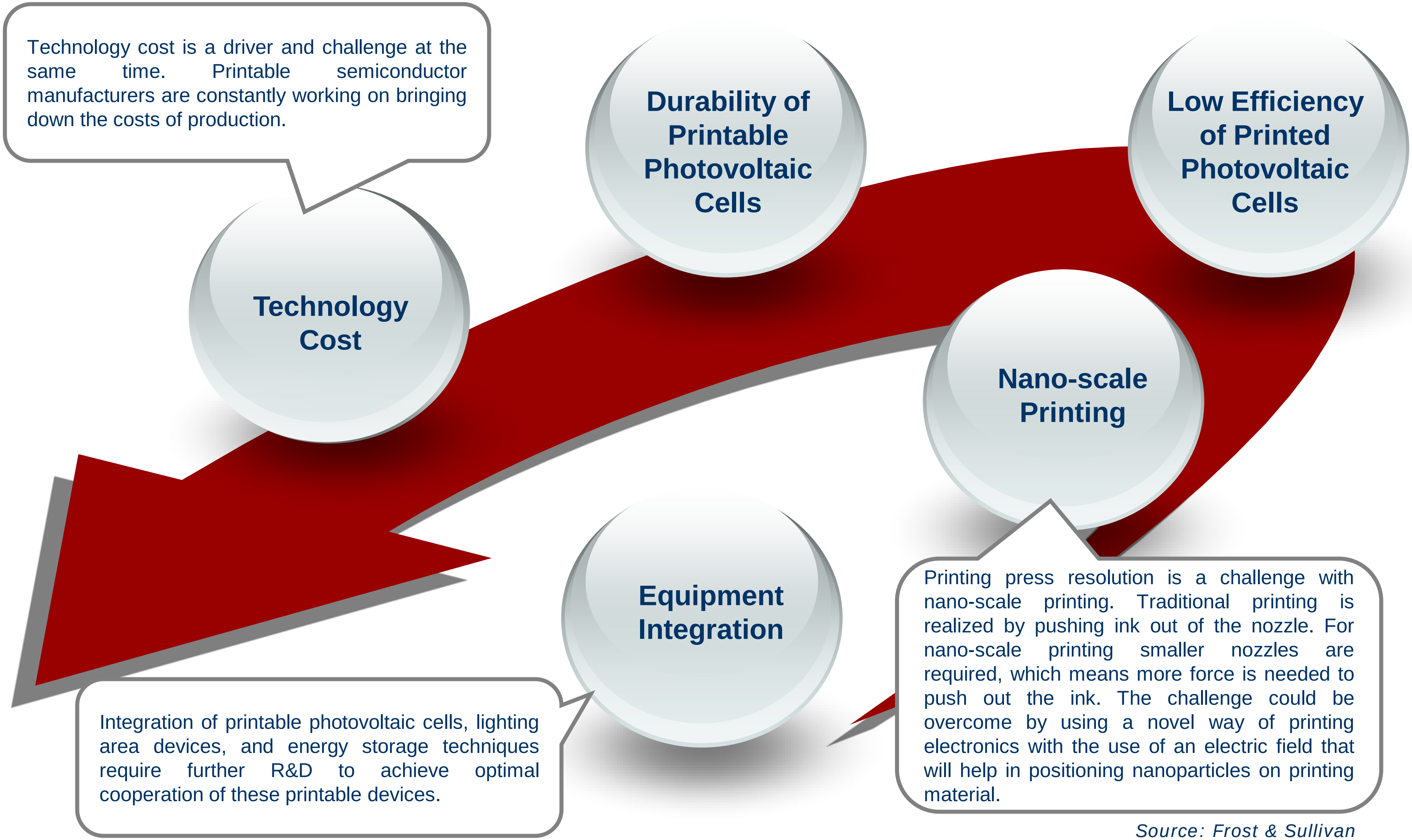
Reducing Aircraft Operation Cost

More efficient decentralized lighting systems require less energy than traditional lighting systems, which will directly translate in to cost savings for airlines. The cost of lighting with the use of printable semiconductor technology could be an order of magnitude smaller than the cost of lighting with standard LED technology.

Final Product Flexibility

LEDs produced via the printing process are bendable, which allows to easily combine them with the existing structure of the given area. This will allow for changing the way in which aeroplanes are lit. In addition, LEDs are the direct lighting source and spreading them on the given area via the printing technique will allow for the effect of area lighting. Another advantage of flexibility is freedom of shape that can be printed. Printable LED area light source is not a single emitter, if more photons are required than more microscopic diodes can be added to the printing ink.

Key Challenges



Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
NthDegree	USA	Next summer the company will start prototype printing solar cells. Right now it is able to print LEDs on a commercial scale while super capacitor technology is still in the development stage and is expected to be commercially available in 12 months time with the efficiency of 12%, which is not so high, but the company is focusing on cost than on efficiency.
xerox	Canada	The company developed printed electronic materials in its research center in Canada. The company is using silver ink to print electronic circuits on plastic, film, or textile materials, which can replace currently used silicon-based electric circuits for application in PV cells and other electronic devices.
IBM	Switzerland, USA	The company is developing a printing technique of ultrasmall nano devices based on semiconductors.

Key Developments (Contd…)

Key Developers	Location	Description of Innovation
University of Illinois at Urbana-Champaign	USA	Researchers from The University of Illinois are developing a novel concept of printers that would be able to print nano-scale electronic devices. They developed electrohydrodynamic inkjet (e-jet) printing that pull the ink in to the printing material rather than push it. Such a solution will decrease the energy needed for manufacturing nano-scale printing electronic devices.
Shrink Nanotechnologies	USA	The company cooperates with the University of Chicago on developing semiconductor printing technology that could find application in solar cells and other lightweight electronic devices.

Other Developers	Location
Thin Film Electronics	Norway
Purdue University (Discovery Park)	USA
Beneq	Finland
Infiniscale	France
Konarka	USA

Analyst Insights

Combining high-speed printing operation with semiconductor production is a technology that will find application in many more industries than just the aerospace industry--for example, in smart grids or electric vehicles (electricity storage).

Semiconductor printing technology can be used in the development of lighting systems, PV cells and energy storage devices that can be then connected together to create a lightweight system able to produce, store, and use energy, and all of the required elements of such a system could be printed.

Lightweight printable electronic technology can potentially help in solving problems of electricity storage faced by many industries in today's world.

Delivering low-cost, lightweight electronic devices to the aerospace industry is a crucial factor that can decide the future of the aerospace energy sector.

VII. Aircraft On-Board Energy Storage

Aircraft On-Board Energy Storage – Definition and Rationale

Tech Definition	Energy storage devices for the aerospace industry are mostly batteries. Some research on super capacitors are also undertaken.
Pertinent Themes	• Aircraft Weight • Aircraft Range • Aircraft Pollution Limitation • Fuel Economy • System Integration • Aircraft Robustness • Energy Density
Importance	Batteries are the most important part of electric, solar, and hybrid planes. Devices able to store electric energy that can be further used for the purpose of powering electric engines are the crucial factors impacting plane range, economy, and/or cost of manufacturing.

Technology Intelligence

Aircraft on-board electric energy storage devices are providing energy for powering electric motors in electric or hybrid planes and store excess energy in solar planes.

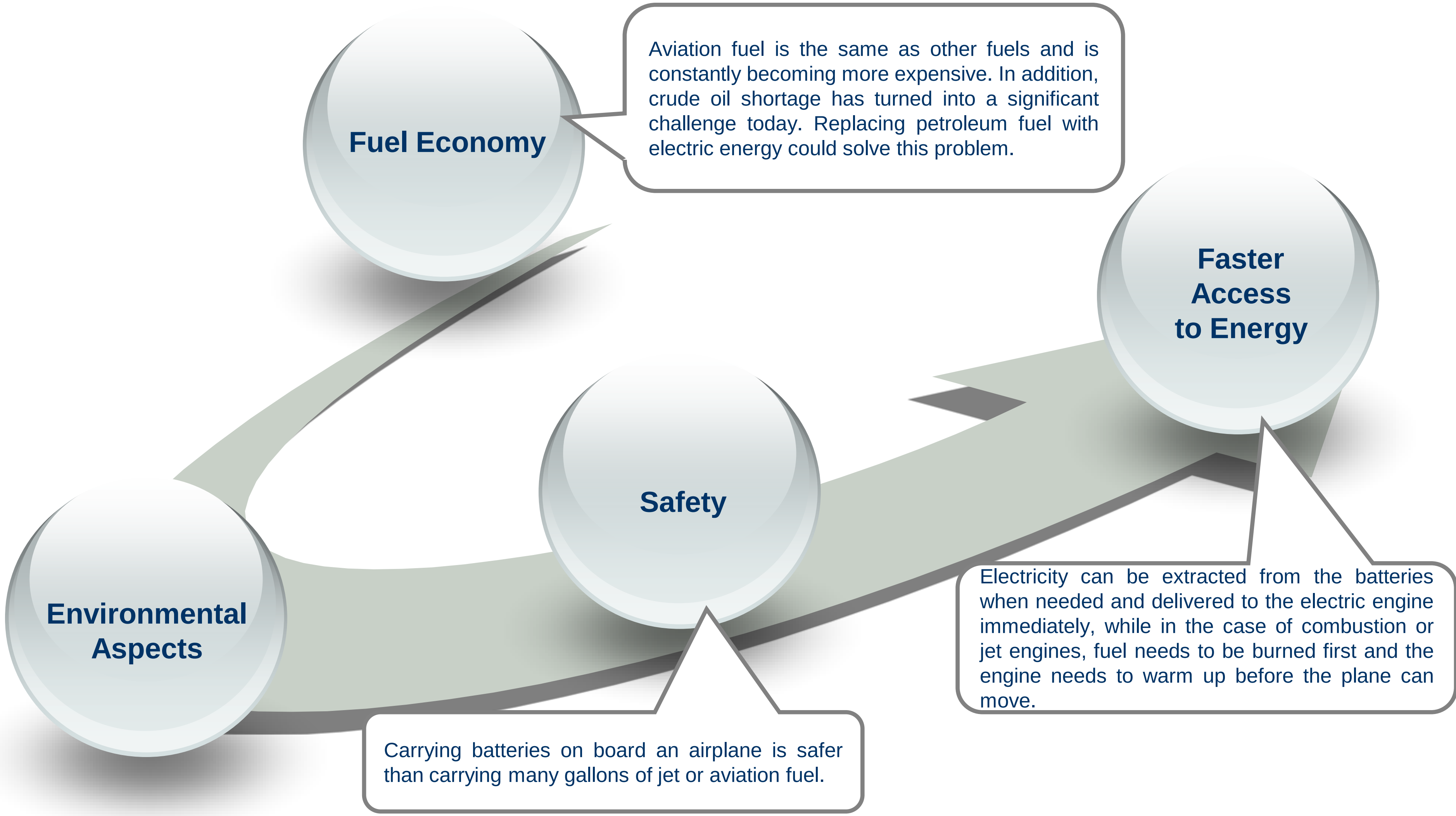
The most popular batteries storage technologies in the aerospace industry are based on lithium-polymer and lithium- ion technologies.

Electric energy stored in batteries can replace energy from burning fuel carried in aircraft tanks.

Some researchers are studying and testing the use of super capacitors as an electricity storage device that can provide higher energy density and be much lighter than batteries.

Energy storage technology is crucial not only for the development of electric planes, but also in smart grids, electric/hybrid cars and other industries.

Key Drivers



Source: Frost & Sullivan

Key Challenges

Cost

Solutions using electricity stored in the batteries are still more expensive than simply burning fuels and using jet or internal combustion engines in the aerospace industry.

Weight

The aerospace industry strives to make aircraft as light in weight as possible. Battery packs are rather heavy devices when compared to fuel tanks that can provide the same amount of energy. Further research in this domain is required.

Lifetime

The number of possible cycles (charging – discharging) needs to be improved for increasing battery lifetime and thus battery economic attractiveness.

Energy Density

This is a very important factor that decides battery size. The more the energy density (W per battery volume), the smaller the area the battery will occupy. This is very important especially in the aerospace energy industry in which aircraft size is a crucial factor.

Charging Time

One of the biggest disadvantages of the batteries is the time needed for its charging, which is often counted in hours. Fast charging stations are required here, but such a technology could have a negative impact on battery lifetime.

Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
PANACIS	Canada	Panacis is a company that develops battery storage systems for grid and aerospace applications. Its battery pack for the Cesna aircraft will be about 800 pounds in weight while storing almost 60 kW of energy. The gas tank that will be replaced by the battery pack weighs about 500 pounds, but the combustion engine weighs about 300 pounds and the electric engine is much lighter and less complicated device. Using this solution delivered by Panacis, the electric Cesna compared with the traditional Cesna is 100 pounds lighter with a 2 h plane range (similar to the traditional Cesna powered by aviation fuel). Besides batteries for fully electric airplanes, the company is also developing 'engine-start' batteries that are lighter than traditional batteries in this field and can deliver more energy, which allows for decreasing traditional aircraft weight. This will allow carrying more cargo or equipment, which is very important in military applications.
Kokam Great Power for Everyone	Korea	The company is delivering lithium-polymer battery packs for the French company Electravia, which is developing electric aircraft. Kokam batteries deliver high power and high energy density of 200 Wh/kg on a wide temperature range of -30 degrees C to 60 degrees C.

Key Developments (Contd…)

Key Developers	Location	Description of Innovation
NthDegree	USA	The company is developing printable super capacitors that are able to store more energy per kilogram than currently used batteries. These also have a slow discharge ability. In addition, the durability is increased to a few thousand of charge/discharge cycles compared to batteries. The company is able to print its super capacitors, which significantly decreases production costs and increases productivity scaling up abilities. NthDegree super capacitors are also lighter than batteries, which would make them suitable for aerospace application with further development. The prototype version of this device is expected in 2012.
CONCORDE …the heart of your system	USA	The company is developing lead-acid batteries (VRB) for aircraft, marine, medical, telecommunication, emergency backup and photographic applications. In addition, it delivers flooded lead-acid batteries for commercial and military aircraft.

Analyst Insights

Replacing fuel tanks and combustion engines with batteries and electric engines will significantly decrease pollution emitted by aircraft in to the atmosphere.

Batteries are the key element for further successful development of electric, hybrid, and solar aircraft industries as well as for other areas such as smart grids or electric/hybrid cars.

Engine-start batteries (such as those developed by Panacis) are finding currently finding application and help in decreasing the weight of aircraft and helicopters, which is very important, especially for military applications.

Too long charging time (besides weight and capacity) is one of the most important disadvantages of batteries.

Lightweight, robust, and easy to produce super capacitors could replace heavy and short lifetime batteries in the future. However, further development and tests are needed in this domain.

Batteries will be one of the most important elements for developing industries (including aerospace).

Energy storage systems are constantly improving and commercially available solutions would fulfil small aerospace industry requirements if expected in the next five years.

VIII. Novel Energy Solutions in Unmanned Aerial Vehicles (UAV)

Novel Energy Solutions in Unmanned Aerial Vehicles (UAV) – Definition and Rationale

Tech Definition	UAVs are airplanes that are remotely controlled and do not need a pilot.
Pertinent Themes	• Aircraft Weight • Aircraft Range • Aircraft Pollution Limitation • Aircraft Noise
Importance	The most important attributes of UAVs are range and level of noise emitted to the atmosphere.

UAVs are used mostly by military, search and rescue teams, and the homeland security industry. They can carry cameras, sensors or other equipment used for monitoring and information collecting and end sending.

The most important factor is the aircraft's ability to stay in the air for the longest possible time without the necessity of refueling or recharging. In addition, noise emission is very important from the military applications point of view.

The ability of staying long in the air is especially important from the security point of view. UAVs are often used, for example, in country border monitoring and constantly sending pictured or vide streams to the base.

Novel solutions for delivering energy to the UAVs including batteries and fuel cells as well as solar energy.

In the case of batteries powered UAVs, lithium-polymer or lithium-ion technology is usually used. In the case of hydrogen powered UAVs, proton exchange membrane (PEM) fuel cells are used (the same as in the automotive industry).

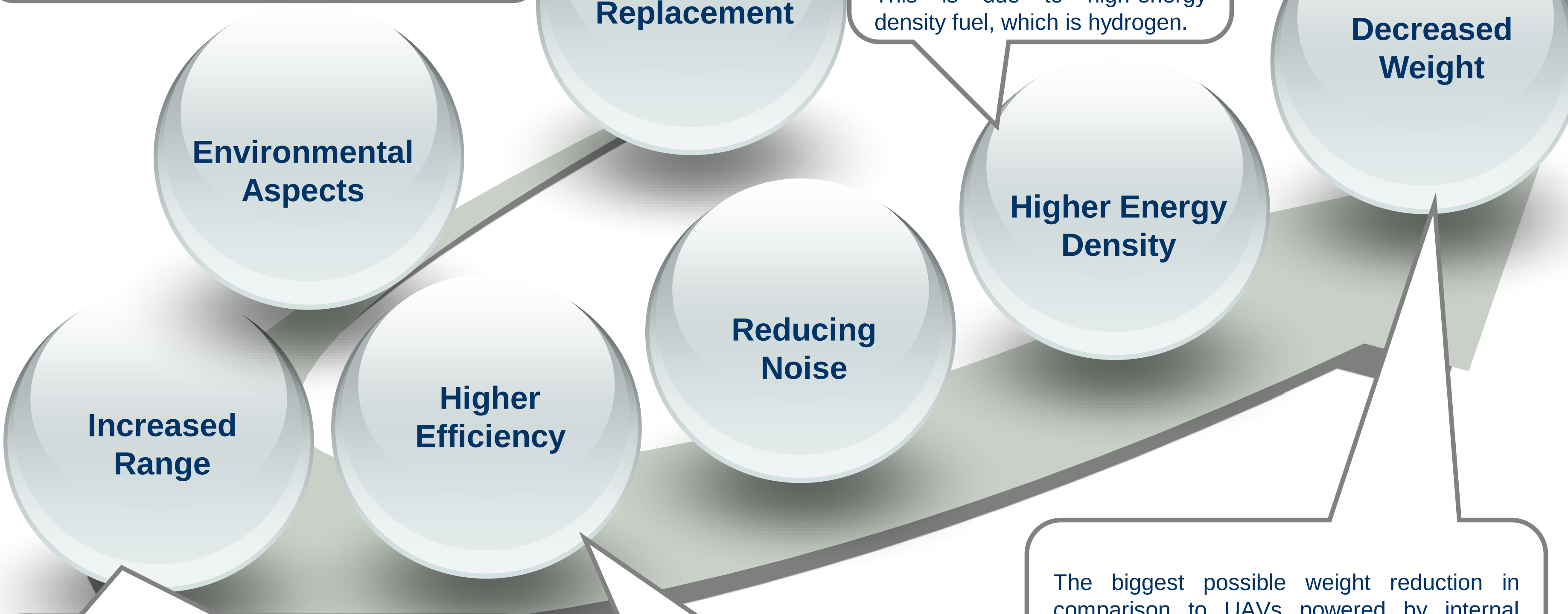
industry).

Energy storage technology is crucial not only for the development of electric planes, but also in smart grids, electric/hybrid cars and other industries.

Key Drivers

Using energy that comes from batteries, solar cells or fuel cells will allow for the elimination of fossil fuel from UAVs supply chain, which could bring about cost savings in operation.

In the case of fuel cell powered UAVs, the achieved energy density is seven times higher than in the case of batteries. This is due to high-energy density fuel, which is hydrogen.



Solar-energy-based UAVs equipped in battery packs are able to stay in the air for weeks. Such vehicles during a night use the energy stored in the batteries that are charged by the solar panels attached to the UAVs' wings.
Fuel cell powered UAVs can stay in the air for more than 24 h.

PEM fuel cells have about four times higher efficiency than internal combustion engines.

The biggest possible weight reduction in comparison to UAVs powered by internal combustion engines can be achieved by implementing fuel cells.

Source: Frost & Sullivan

Key Challenges

Bigger Size (in some cases)

Using solar energy for powering UAVs brings the advantage of length of duration that the plane can stay in the air. However, the area required for solar panels in this case is quite large and UAVs will be larger than their equivalent with internal combustion engines.

Higher Initial Costs

Fuel cells as well as solar power are not as mature and broad technologies as internal combustion engines. Hence, the initial cost of UAVs equipped with fuel cells or solar/battery propulsion systems will be higher than currently used UAVs based on the fossil fuel burning propulsion system.

Lifetime

Battery, solar panel and fuel cell lifetime (10 years to 15 years) is not as long as internal combustion engines (15 years to 20 years).

Safety

On-board hydrogen storage (in the case of fuel cell UAVs) carry a security risk since hydrogen is a very easily flammable and explosive gas, which in addition needs to be stored in high-pressure containers.
With solar planes there is always a risk connected to weather conditions and the availability of sunlight.

Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
United States Naval Research Laboratory	USA	The company developed the Ion Tiger, which is a UAV powered by PEM fuel cells. The Ion Tiger can carry 1.8 kg to 2.4 kg of equipment and its total weight is around 17 kg. On-board the UAV 550W (0.75 hp) fuel cells are placed. The UAV developed by the Naval Research Laboratory can stay in the air for more than 26 h. The next step of the researchers will be to increase the fuel cell power to 1.5 kW (2 HP), which will allow for increasing the flight time to three days and carrying more equipment.
BlueBird Aero Systems	Israel	The company developed the Boomerang, which is the first hydrogen powered UAV that is available commercially today. The Boomerang uses PEM fuel cells as a source of electric energy delivered by Horizon Fuel Cell Technologies. The fuel cell has 2 kg weight and is able to deliver 900 Wh of energy. The total weight of the UAV is just 9 kg.
QinetiQ	UK	The company developed the Zephyr, which is a solar UAV that proved its performance in over 14 days of continuous flight.
Lockheed Martin — We never forget who we're working for™	USA	The company is very active in the UAV industry. It develops a number of concept models that include a UAV that is powered fully by electric energy.

Other Developers

Other Developers	Location
AC Propulsion – USA	USA
University of Missouri-Rolla	USA
DLR Institute of Flight Systems (German Aerospace Center)	Germany
Swiss Federal institute of Technology Zurich	Switzerland
York University	UK
NASA	USA
Israel Aerospace Industries	Israel
Northrop Grumman	USA

Analyst Insights

UAVs have a huge importance and application in military, homeland security, rescue and searching industries. Decreasing its noise, cost of operation, and robustness will be up on the interest of the above mentioned industries.

Solar-powered UAVs can stay in the air for a lengthy period of time. However, this is not the case in all weather conditions and their sizes are increased when solar panels have to be placed in them.

All of the above-mentioned novel technologies for UAVs will significantly decrease vehicle noise and pollution emission in to the atmosphere as compared to units equipped with internal combustion engines.

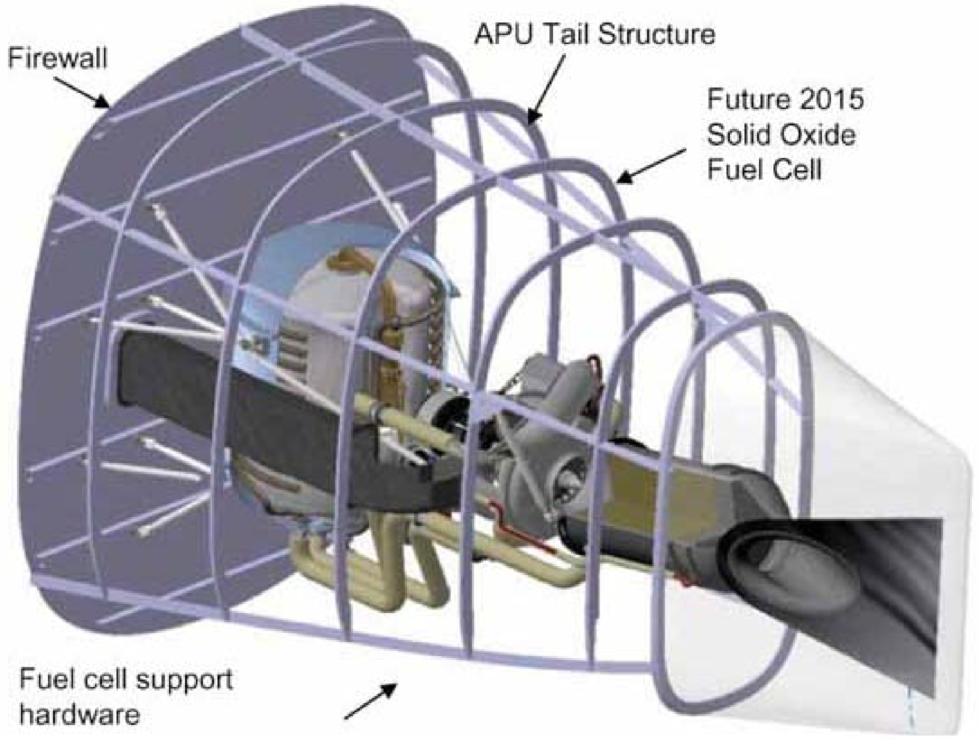
Fuel-cell-powered UAVs are more reliable, smaller, and lighter than solar-powered UAVs. However, its range could be smaller than in the case of solar vehicles.

Fuel-cell-powered UAVs are lighter and smaller than solar-powered units, and hence this solution will find wide application in the military industry.

Solar-powered UAVs, however, can be useful for homeland security applications due to their ability to stay in the air for a long time.

IX. Fuel Cell as an Auxiliary Power Unit (APU)

Hybrid SOFC APU installation concept



Source: Boeing

Fuel Cell as an Auxiliary Power Unit (APU) – Definition and Rationale

Tech Definition	The APU is an independent device that provides power to the vehicle other than propulsion.
Pertinent Themes	• Aircraft Reinforcement • Aircraft Pollution Limitation • Aircraft Noise
Importance	APUs can be commonly found on-board large aircraft and some large land vehicles.

APUs are used as an independent power source on-board the aircraft for the purpose of starting the engine or powering other on-board electronics and equipment.

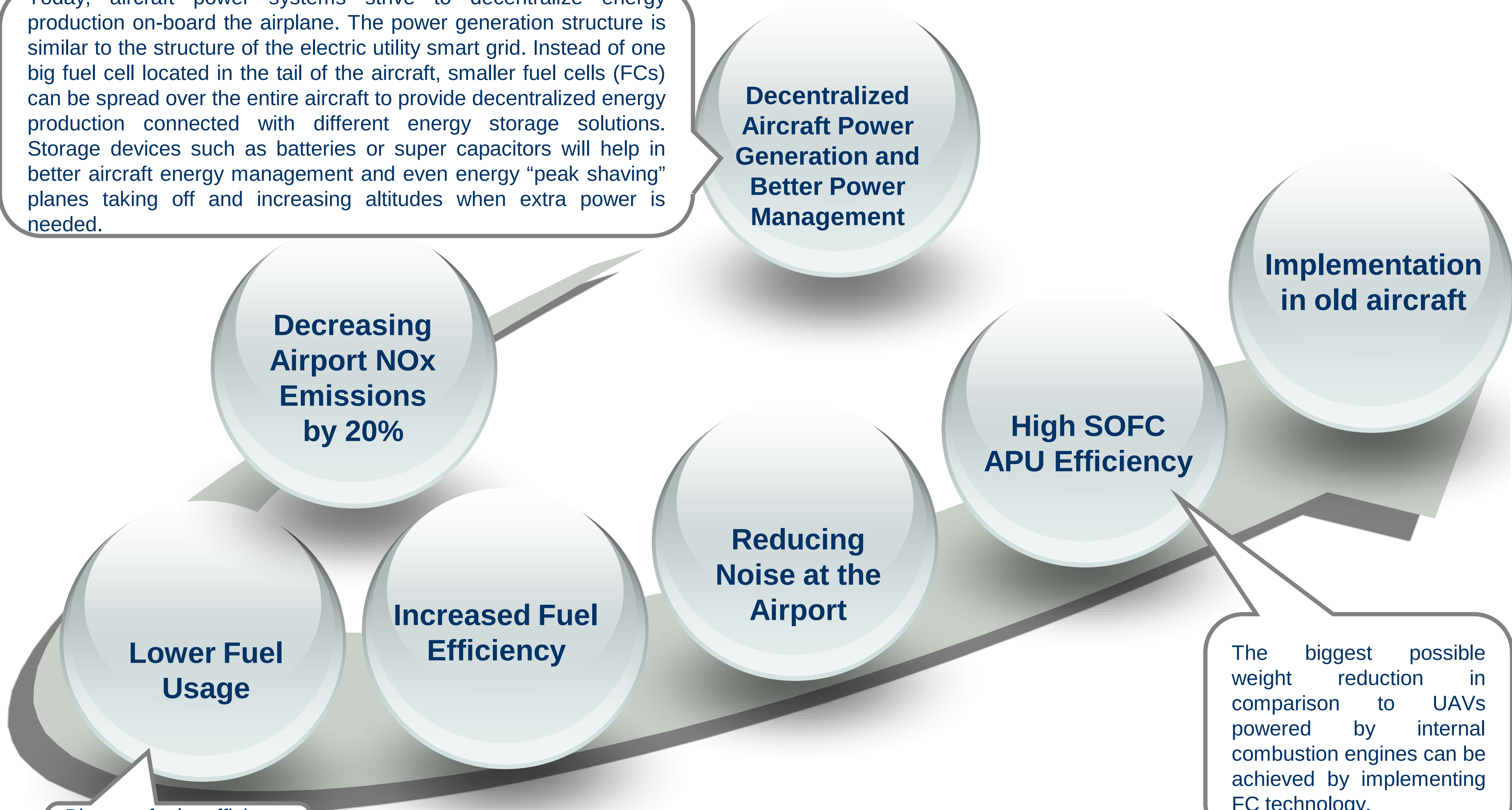
Researchers are testing solid oxide fuel cells (SOFCs) as an APU. SOFCs have been chosen because they can use the same fuel as plane engines so no other energy medium on-board is needed.

One of the fuel cell by-products is water that can be used on-board the airplane for cleaning or sanitary purposes.

APUs are currently used mostly for delivering power necessary for starting the plane’s engines. During the flight, all on-board electronics and other devices are powered by energy produced from generators driven by jet engines. The more the number of devices that need to be powered, the more fuel will be burned by the engine during the flight. Fuel cell technology as an APU can change this situation.

Key Drivers

Today, aircraft power systems strive to decentralize energy production on-board the airplane. The power generation structure is similar to the structure of the electric utility smart grid. Instead of one big fuel cell located in the tail of the aircraft, smaller fuel cells (FCs) can be spread over the entire aircraft to provide decentralized energy production connected with different energy storage solutions. Storage devices such as batteries or super capacitors will help in better aircraft energy management and even energy "peak shaving" planes taking off and increasing altitudes when extra power is needed.



The biggest possible weight reduction in comparison to UAVs powered by internal combustion engines can be achieved by implementing FC technology.

Bigger fuel efficiency will result in lower plane fuel usage.

Source: Frost & Sullivan

Key Challenges

High Operation Temperature of SOFCs

Removing heat from the airplane is always a challenge for aircraft manufacturers. SOFCs produce more heat than APUs used today. Using PEM fuel cell (PEMFC) technology could solve this problem, but it also creates a new one--storing hydrogen on-board the airplane and the space required for this purpose.

Slower SOFC Start

SOFCs need some time to warm up, which results in more time needed to start operations than that required for currently used APUs.

System Durability and Reliability

Fuel Storage Infrastructure

Decentralized power generation will need specific fuel tank infrastructure that will ensure fuel supply to all energy generators (FC) on board.

FC System Integration

This challenge is connected with environmental, power quality, maintenance and reliability considerations that need to be taken in to account while integrating FCs with the aircraft.

Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
Boeing	USA	The company is strongly investing in the development of clean and efficient solutions in the aerospace energy sector. It is focusing its R&D efforts on SOFC APUs and decentralized aircraft power systems using FC technology. Boeing is the largest company that currently works on development in the area of SOFC APU technology. The company is currently testing its system.
NEXTECH MATERIALS	USA	The company is developing SOFCs that could work as an APU in the transportation and aerospace industry. The company has been awarded with $2 million support by the US Commerce Department Advanced Technology Program (ATP); in addition Ohio's Third Frontier Fuel Cell Program (TFFCP) adds $898,137 for the company's further technology development. Nextech Materials cooperates with SOFCo-EFS Holdings LLC; Edison Materials Technology Center; and NASA Glenn Research Center.
AIRBUS AN EADS COMPANY	France, UK	Airbus is cooperating with UK company Intelligent Energy, which is focusing on the development of clean and efficient power sources. Companies are working on APUs that will be based on FC technology using hydrogen (PEMFC) or hydro-carbons (SOFC) fuels.

Analyst Insights

Currently used commercial aircraft need around 1 MW of electric power, while older technology aircraft from 15 years to 20 years ago needed only 100 kW or less. Today's aircraft have more devices and systems powered by electricity.

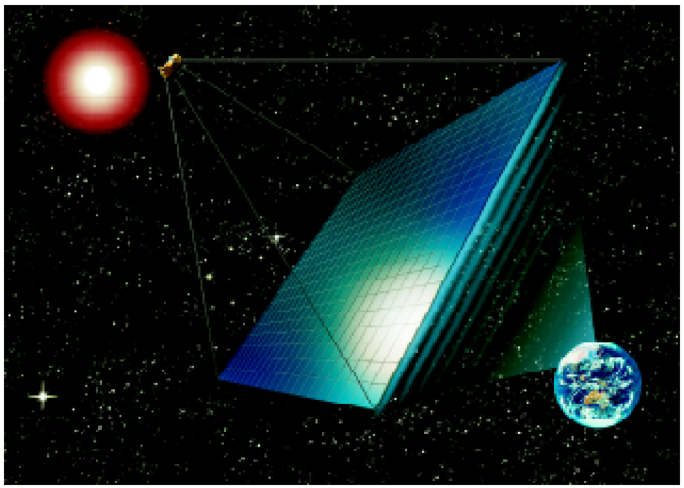
Some solutions are using heat produced by SOFC APUs to drive the generator and produce additional electricity on-board the aircraft. SOFC APUs in such applications has an efficiency of 60% to 70%, while APUs used today in airplanes have an efficiency of around 17%.

Today, APUs are considered as a backup source of energy or as devices that help in starting the main engine of the aircraft. In the future (5 years to 10 years from now) APUs could be a power supply unit for the aircraft's electric devices.

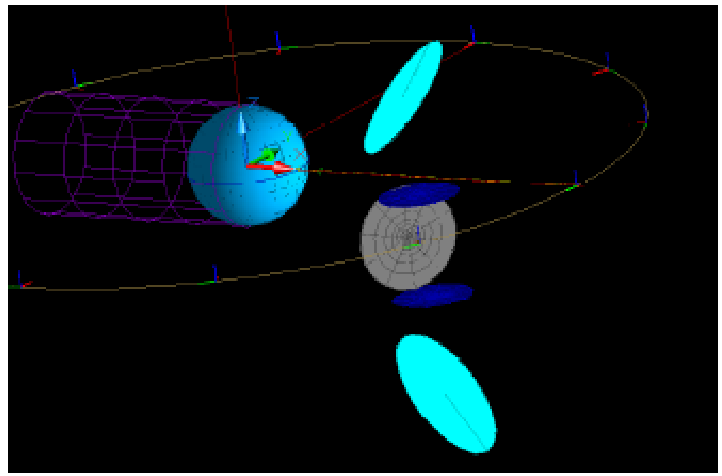
FC decentralized APUs could take part of the load off from the main aircraft engines.

Boeing is closest to the successful development of FC APUs with the aim to realize its concept for decentralized smart aircraft power generation and management in the next 5 years to 10 years.

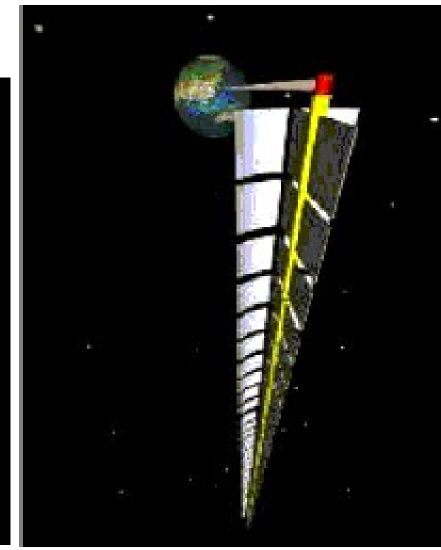
X. Space Solar Power System



(a) Microwave Basic Model (USEF)



(b) Microwave Advanced Model (JAXA)



(c) Laser Model (JAXA)

Source: JAXA

Space Solar Power System – Definition and Rationale

Tech Definition	The concept of the space solar power system (SSPS) is based on harvesting solar energy by PV cells sent to space and sending produced energy to the ground.
Pertinent Themes	• Solar Energy • Energy Transmission • Photovoltaic • Microwave • Lasers • Energy Production in Space
Importance	Photovoltaic panels in space could produce energy constantly since sunlight could be available 24 h per day.

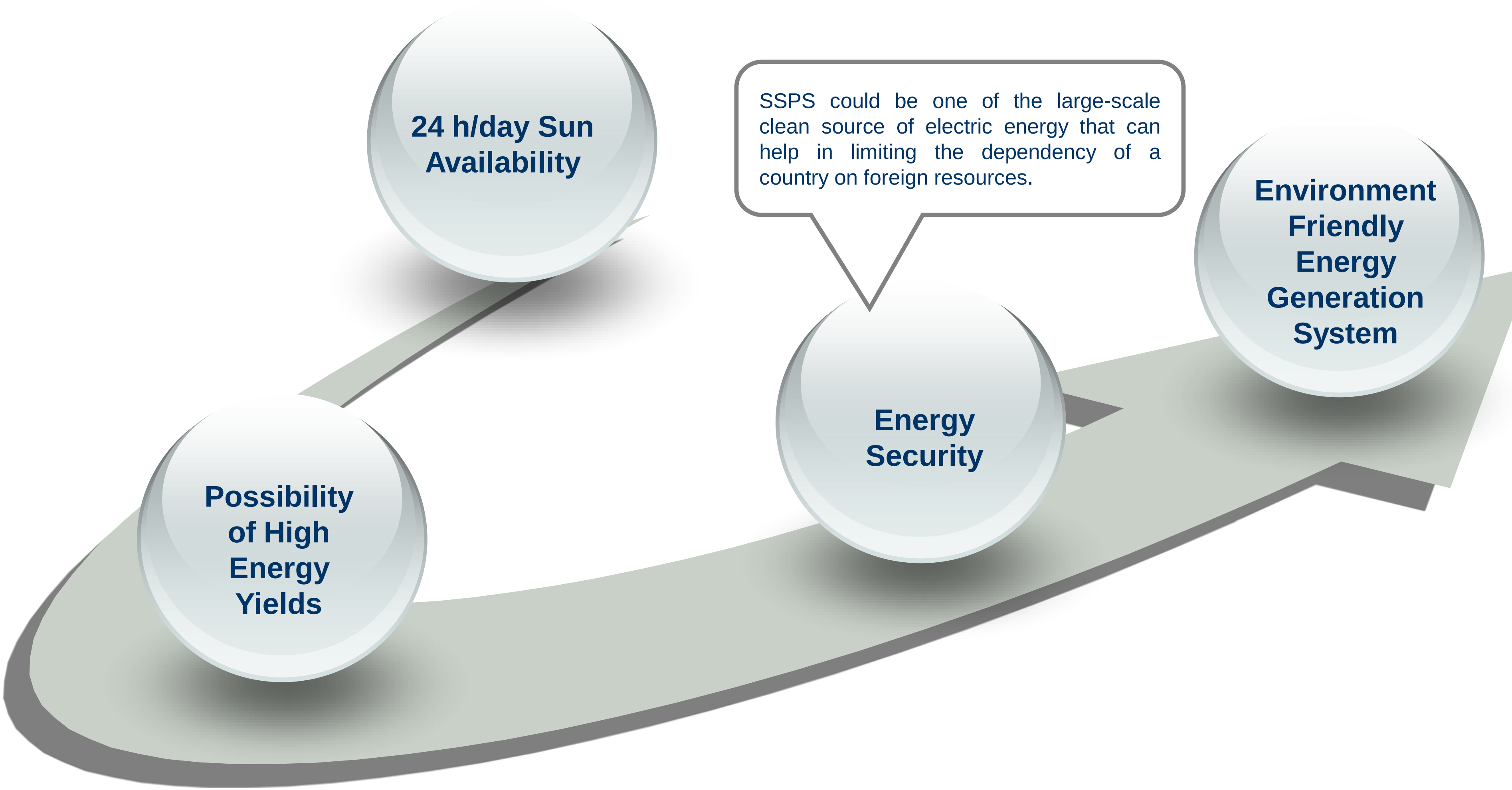
The sunlight spectrum will be different in space than on the ground and PV cells need to be optimized in a proper manner for the purpose of maximizing cell sunlight to electricity conversion.

In space, higher cell effectives are possible due to the absence of atmosphere or clouds that weaken solar radiation. In addition sunlight is available 24 h per day.

Two methods of wireless electric energy transmission from space to the ground are considered. One is using microwave technology and other is using laser beam technology.

In the case of microwave technology, energy could be received by the ground microwave stations and in the case of laser transmission by PV cells. Advanced laser beam guide systems will ensure proper beam aiming on the PV arrays on the ground.

Key Drivers



Source: Frost & Sullivan

Key Challenges

Space Operation System

Space generation electric power systems will continually operate in the environment, which is completely different on the ground. Long-term tests are needed to determine the optimum operation parameters and materials that will be used to build the final device.

Large Space Structure

Commercial space solar electric power generation facility is expected to have 1 GW capacity, which will require large structure. Long-term tests providing data on the behavior of such a structure in space conditions are required.

Development of Highly Efficient Devices for Microwave Power Transmission

Development of high-efficiency amplifiers, phase shifters, and rectifying antennas are required for microwave power transmission medium.

Development of Highly Efficient Devices for Laser Power Transmission

Development of new source crystal and high-efficiency receivers are required for laser power transmission. In addition, control of power beaming needs further improvements as well.

High R&D Costs

Approximately $10 billion for a 10-year research and test program.

Source: Frost & Sullivan

Key Developments

Key Developers	Location	Description of Innovation
Japan Aerospace Exploration Agency	Japan	JAXA is developing a space solar power system that generates electric power by using PV cells. The researchers are currently testing on-the-ground systems for transmission of energy via microwaves and laser beams in parallel. By the end of 2013, these tests should be completed, and based on the collected data, a small pilot space project will be developed and put in to operation around 2016. The introduction of the pilot demonstration project is expected in the year 2020. Based on data provided by this pilot space project, the researchers will decide which wireless transmission technology will be more suitable (laser, microwave). The commencement of construction of the first worldclass commercial-scale 1GW SSPS is expected by the end of 2030. Japanese researchers have started physical tests already.
SPACE ENERGY	Switzerland	The company is planning to develop and operate space satellites that will be able to harvest space solar energy and send it into the Earth's surface. The company is considering microwave wireless power transmission to the Earth.
Ministry of Defence Government of India; Department of Defense United States of America	USA, India	The Indian and US governments together plan to develop a space power generation system based on microwave transmission. Researchers have plans to develop and deploy a working space solar power generation system by the end of the year 2025.

Analyst Insights

SSPS is a technology that can provide clean electricity on a mass scale to the place on Earth where it is needed.

Developments in wireless power transmission for the SSPS project will find application in commercial power devices such as vehicles, personal computers, mobile phones or battery-less sensors. Good and reliable wireless power transmission technology for on-the-ground application is expected in several years.

Very high financial resources are needed ($10 billion for a 10-year research project) to accelerate R&D for SSPS technology.

Further long-term tests, economic attractiveness, and social acceptance (safety) will determinate which particular technology will be the most suitable.

Commercial-scale Solar Space Power System is expected not earlier than in 2030.

But particular developments in this domain can find application in today's world.

Key Patents; and Contacts

Key Patents

United States Patent 7,327,105

Publication Date: February 5, 2008

Mesh connected electrical rotating machine with span changing

Abstract

An electrical rotating apparatus is provided that has variable impedance. This is achieved by connecting one of the polyphase components of the apparatus in a mesh connection. The spanning value, L, of such a mesh connection may be varied by changing the harmonic content supplied by an inverter component. Also provided is a method for connecting an inverter to a motor, wherein a switching arrangement permits the simple alteration between various mesh connections of different span value, changing thereby the Volts/Hertz ratio of the motor.

Inventors: Edelson; Jonathan Sidney (Portland, OR)

Assignee: Borealis Technical Limited (GI)

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US Application No.: 20100068839

Publication Date:14.09.2006

Method of manufacturing a light emitting, photovoltaic or other electronic apparatus and system

Abstract

The present invention provides a method of manufacturing an electronic apparatus, such as a lighting device having light emitting diodes (LEDs) or a power generating device having photovoltaic diodes. The exemplary method includes forming at least one first conductor coupled to a base; coupling a plurality of substrate particles to the at least one first conductor; converting the plurality of substrate particles into a plurality of diodes; forming at least one second conductor coupled to the plurality of spherical diodes; and depositing or attaching a plurality of substantially spherical lenses suspended in a first polymer, with the lenses and the suspending polymer having different indices of refraction. In some embodiments, the lenses and diodes have a ratio of mean diameters or lengths between about 10:1 and 2:1. In various embodiments, the forming, coupling and converting steps are performed by or through a printing process.

Inventors: Richard A. Blanchard William Johnstone Ray Mark David Lowenthal Neil O. Shotton Mark Allan Lewandowski Kirk A. Fuller Donald Odell Frazier

Assignee: NTHDEGREE Technologies Worldwide Inc.

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Key Patents (Contd…)

US Application No.: 20090284179

Publication Date:11-19-2009

Apparatuses for providing power for illumination of a display object

Abstract

An exemplary power regulator apparatus provides power for illumination of a display object, such as a merchandise package or container, which has a light emitting apparatus comprising a secondary inductor and an illumination source. A support structure, such as a point of purchase display, typically contains or supports one or more power regulators and display objects. The power regulator comprises a controller and a primary inductor, and the controller is adapted to provide a voltage or current to the primary inductor to generate a primary inductor voltage. The controller may also comprise a plurality of switches and a memory adapted to store values for switching frequency or switch on-time durations or pulse widths. The illumination source emits visible light when the power regulator is in an on state and when the secondary inductor is within a predetermined distance of the primary inductor.

Inventors: William Johnstone Ray Mark D. Lowenthal David R. Bowden Peter Michael Bray

Assignee: NTHDEGREE Technologies Worldwide Inc.

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United States Patent 7380749

Publication Date:06/03/2008

Combined fuel cell aircraft auxiliary power unit and environmental control system

Abstract

Combined aircraft hybrid fuel cell auxiliary power unit and environmental control system and methods are disclosed. In one embodiment, an auxiliary power unit includes a fuel cell component which chemically converts combustible fuel into electrical energy. Unutilized fuel emitted by the fuel cell component is combusted by a burner to generate heated gas. The heated gas is received by and drives a turbine, which in turn drives a drive shaft. A compressor, coupled to the drive shaft, compresses a source of oxidizing gas for supplying compressed oxidizing gas to the fuel cell component and to an environmental control system. A heat exchanger controls the temperature of the pressurized air leaving the environmental control system to provide the cabin air supply. Finally, a generator is coupled to the drive shaft to be driven by the turbines to generate additional electrical energy.

Inventors: Fucke; Lars (Kirkland, WA, US), Daggett; David L. (Snohomish, WA, US)

Assignee: The Boeing Company (Chicago, IL, US)

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Key Patents (Contd…)

International Application Publication No: WO2010146045 (A1)

Publication Date: 2010-12-23

Drive system for aircraft on the ground

Abstract

The invention relates to a drive system for an aircraft, comprising an electric motor. With the aim of allowing aircraft to be driven on the ground more efficiently and also more quietly, the invention provides that the electric motor is designed to drive at least one wheel of a landing gear of the aircraft and to move the aircraft by driving the at least one wheel with at least partial adhesion to the ground. The invention also relates to an electrical power routing system for a taxiway area of an airfield, comprising an element which carries current, which is arranged along the taxiway and is designed to pass electrical power for operation of an electrical machine to a drive system for at least one aircraft; and at least one contact-making apparatus, which is designed to make an electrically conductive connection between the current-carrying element and the aircraft on the taxiway.

Inventors: Foerst Klaus [DE]

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US Application Publication US2010213309 (A1)

Publication Date: 2010-08-26

Non-planar adaptive wing solar aircraft

Abstract

A system and method for assembling and operating a solar powered aircraft, composed of one or more modular constituent wing panels. Each wing panel includes at least one hinge interface that is configured to rotationally interface with a complementary hinge interface on another wing panel. When a first and second wing panel are coupled together via the rotational interface, they can rotate with respect to each other within a predetermined angular range. The aircraft further comprises a control system that is configured to acquire aircraft operating information and atmospheric information and use the same alter the angle between the wing panels, even if there are multiple wing panels. One or more of the wing panels can include photovoltaic cells and/or solar thermal cells to convert solar radiation energy or solar heat energy into electricity, that can be used to power electric motors. Further, the control system is configured to alter an angle between a wing panel and the horizon, or the angle between wing panels, to maximize solar radiation energy and solar thermal energy collection. A tail assembly for the aircraft includes a rotational pivot that allows the flight control surfaces to rotate to different orientations to avoid or reduce flutter loads and to increase solar radiation energy and/or solar thermal energy collection from photovoltaic cells and/or solar thermal cells the can be located on the tail structure associated with the flight control surfaces.

Inventors: Parks Robert [US]

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Key Patents (Contd…)

Application Publication No: CA2691612 (A1)

Publication Date: 2008-09-04

Method for cold stable biojet fuel

Abstract

Plant or animal oils are processed to produce a fuel that operates at very cold temperatures and is suitable as an aviation turbine fuel, a diesel fuel, a fuel blendstock, or any fuel having a low cloud point, pour point or freeze point. The process is based on the cracking of plant or animal oils or their associated esters, known as biodiesel, to generate lighter chemical compounds that have substantially lower cloud, pour, and/or freeze points than the original oil or biodiesel. Cracked oil is processed using separation steps together with analysis to collect fractions with desired low temperature properties by removing undesirable compounds that do not possess the desired temperature properties.

Inventors: Aulich Ted [US]; Seames Wayne [US]

Applicants: Univ North Dakota [US]

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US Application Publication US2006278757 (A1)

Publication Date: 2006-12-14

Method and device for launching aerial vehicles

Abstract

A heavier-than-air air vehicle, particularly a long endurance, solar powered, unmanned aerial vehicle (UAV) intended for "perpetual" flight within the stratosphere, is carried to its operational altitude suspended on a tether from a helium balloon. The tether is attached at or towards a tip of the UAV's wing so that it is carried in effectively a 90 DEG banked attitude. At the desired altitude the UAV's powerplant is started and it flies on its tether in an upwardly-spiralling path relative to the balloon until a level or near level attitude is attained, when the tether is released and the UAV is permitted to assume free flight.

Inventors: Kelleher; Christopher C. [GB]

Assignee: QINETIQ Ltd.

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Decision Support Database

Decision Support Database – Worldwide Number of Airports

Decision Support Database

Table: Number of Airports

Region / Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	CAGR % (2007 - 2014)
North America												
Canada	1,326.0	1,331.0	1,337.0	1,343.0	1,350.0	1,359.0	1,370.0	1,381.0	1,395.0	1,411.0	1,429.0	0.89
United States	14,857.0	14,893.0	14,858.0	14,947.0	15,063.0	15,193.0	15,348.0	15,521.0	15,710.0	15,920.0	16,157.0	1.12
TOTAL	**16,183.0**	**16,224.0**	**16,195.0**	**16,290.0**	**16,413.0**	**16,552.0**	**16,718.0**	**16,902.0**	**17,105.0**	**17,331.0**	**17,586.0**	**1.10**
Latin America												
Argentina	1,334.0	1,333.0	1,381.0	1,272.0	1,180.0	1,104.0	1,036.0	977.0	928.0	886.0	851.0	(5.58)
Brazil	4,136.0	4,223.0	4,276.0	4,263.0	4,263.0	4,266.0	4,268.0	4,268.0	4,269.0	4,270.0	4,271.0	0.03
Chile	364.0	363.0	363.0	358.0	358.0	358.0	358.0	358.0	360.0	360.0	360.0	0.08
Mexico	1,833.0	1,832.0	1,839.0	1,834.0	1,837.0	1,838.0	1,841.0	1,844.0	1,844.0	1,847.0	1,848.0	0.11
Peru	234.0	246.0	268.0	237.0	237.0	238.0	239.0	240.0	242.0	243.0	244.0	0.42
Venezuela	369.0	370.0	375.0	390.0	390.0	390.0	392.0	394.0	394.0	396.0	396.0	0.22
TOTAL	**8,270.0**	**8,367.0**	**8,502.0**	**8,354.0**	**8,265.0**	**8,194.0**	**8,134.0**	**8,081.0**	**8,037.0**	**8,002.0**	**7,970.0**	**(0.67)**
Asia - Pacific												
Australia	448.0	450.0	455.0	461.0	461.0	461.0	461.0	462.0	462.0	463.0	463.0	0.06
China	472.0	478.0	486.0	467.0	469.0	472.0	477.0	481.0	484.0	489.0	493.0	0.78
Hong Kong	4.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.00
India	333.0	334.0	341.0	346.0	347.0	349.0	349.0	350.0	352.0	352.0	354.0	0.33
Indonesia	667.0	668.0	662.0	652.0	652.0	653.0	654.0	655.0	656.0	657.0	657.0	0.11
Japan	174.0	173.0	175.0	176.0	177.0	178.0	180.0	181.0	181.0	183.0	184.0	0.64
Malaysia	117.0	117.0	117.0	116.0	116.0	117.0	118.0	118.0	119.0	119.0	119.0	0.37
New Zealand	116.0	117.0	118.0	121.0	121.0	121.0	122.0	123.0	123.0	123.0	124.0	0.35
Philippines	255.0	256.0	256.0	255.0	255.0	255.0	256.0	256.0	257.0	257.0	257.0	0.11
Singapore	10.0	9.0	9.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	0.00
South Korea	179.0	108.0	107.0	105.0	105.0	105.0	105.0	106.0	106.0	106.0	106.0	0.14
Taiwan	40.0	42.0	42.0	41.0	41.0	41.0	41.0	41.0	42.0	42.0	42.0	0.34
Thailand	109.0	108.0	108.0	106.0	106.0	107.0	108.0	109.0	109.0	109.0	111.0	0.66
TOTAL	**2,924.0**	**2,863.0**	**2,879.0**	**2,856.0**	**2,860.0**	**2,869.0**	**2,881.0**	**2,892.0**	**2,901.0**	**2,910.0**	**2,920.0**	**0.32**
Western Europe												
Austria	55.0	55.0	55.0	55.0	54.0	52.0	52.0	50.0	49.0	49.0	47.0	(2.22)
Belgium	43.0	43.0	43.0	43.0	44.0	44.0	45.0	46.0	47.0	48.0	48.0	1.58
Denmark	97.0	97.0	92.0	91.0	90.0	88.0	88.0	87.0	85.0	84.0	82.0	(1.48)
Finland	148.0	148.0	148.0	148.0	147.0	145.0	144.0	143.0	141.0	141.0	139.0	(0.89)
France	478.0	479.0	477.0	476.0	477.0	478.0	478.0	480.0	481.0	481.0	482.0	0.18
Germany	550.0	552.0	554.0	550.0	549.0	548.0	547.0	545.0	544.0	544.0	543.0	(0.18)
Greece	80.0	82.0	82.0	81.0	82.0	83.0	83.0	84.0	86.0	86.0	86.0	0.86
Iceland	98.0	97.0	98.0	99.0	99.0	100.0	100.0	100.0	101.0	102.0	102.0	0.43
Ireland	36.0	36.0	36.0	34.0	33.0	32.0	31.0	31.0	30.0	29.0	28.0	(2.74)
Italy	134.0	135.0	133.0	132.0	131.0	130.0	129.0	128.0	126.0	126.0	125.0	(0.78)
Luxembourg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.00
Netherlands	27.0	27.0	27.0	27.0	26.0	25.0	24.0	22.0	22.0	21.0	20.0	(4.20)
Norway	101.0	100.0	99.0	98.0	97.0	95.0	94.0	94.0	92.0	91.0	91.0	(1.05)
Portugal	65.0	66.0	66.0	66.0	66.0	66.0	66.0	67.0	68.0	68.0	68.0	0.43
Spain	156.0	157.0	157.0	154.0	155.0	155.0	157.0	157.0	158.0	159.0	159.0	0.46
Sweden	254.0	255.0	255.0	250.0	251.0	252.0	253.0	253.0	253.0	253.0	254.0	0.23
Switzerland	65.0	65.0	65.0	65.0	64.0	63.0	62.0	60.0	60.0	60.0	59.0	(1.37)
United Kingdom	471.0	471.0	471.0	449.0	449.0	451.0	452.0	454.0	455.0	455.0	457.0	0.25
TOTAL	**2,860.0**	**2,867.0**	**2,860.0**	**2,820.0**	**2,816.0**	**2,809.0**	**2,807.0**	**2,803.0**	**2,800.0**	**2,799.0**	**2,792.0**	**(0.14)**
Eastern Europe												
Czech Republic	120.0	121.0	121.0	122.0	123.0	123.0	123.0	125.0	125.0	126.0	127.0	0.58
Hungary	44.0	44.0	46.0	46.0	46.0	45.0	44.0	42.0	42.0	41.0	40.0	(1.98)
Poland	123.0	123.0	122.0	123.0	122.0	121.0	119.0	119.0	119.0	117.0	116.0	(0.83)
Russia	2,586.0	1,730.0	1,623.0	1,260.0	1,204.0	1,154.0	1,109.0	1,071.0	1,037.0	1,008.0	983.0	(3.48)
Turkey	119.0	120.0	117.0	117.0	118.0	119.0	119.0	120.0	120.0	120.0	121.0	0.48
TOTAL	**2,992.0**	**2,138.0**	**2,029.0**	**1,668.0**	**1,613.0**	**1,562.0**	**1,514.0**	**1,477.0**	**1,443.0**	**1,412.0**	**1,387.0**	**(2.60)**
Middle East & Africa												
Egypt	87.0	87.0	88.0	88.0	88.0	89.0	89.0	91.0	91.0	92.0	92.0	0.64
Israel	51.0	51.0	53.0	53.0	52.0	51.0	50.0	49.0	48.0	47.0	47.0	(1.70)
Saudi Arabia	201.0	202.0	208.0	213.0	214.0	214.0	216.0	218.0	218.0	218.0	220.0	0.46
South Africa	728.0	728.0	731.0	728.0	726.0	723.0	722.0	721.0	719.0	718.0	717.0	(0.22)
TOTAL	**1,067.0**	**1,068.0**	**1,080.0**	**1,082.0**	**1,080.0**	**1,077.0**	**1,077.0**	**1,079.0**	**1,076.0**	**1,075.0**	**1,076.0**	**(0.08)**
WORLD TOTAL	**34,296.0**	**33,527.0**	**33,545.0**	**33,070.0**	**33,047.0**	**33,063.0**	**33,131.0**	**33,234.0**	**33,362.0**	**33,529.0**	**33,731.0**	**0.28**

Note: All figures are rounded; the base year is 2007. Source: Frost & Sullivan

Definition

The above table represents the total number of airports. The runway (s) may be paved (concrete or asphalt surfaces) or unpaved (grass, dirt, sand, or gravel surfaces), but must be usable. Not all airports have facilities for refueling, maintenance, or air traffic control.

Note

1. Hyphen indicates non availability of data
2. Figures for 2005, 2006, 2007 are Frost & Sullivan estimates
3. Figures for India are as of April to March each year
4. Regional and World total are calculated using weighted average of countries in the region and are not the simple average

Frost & Sullivan's worldwide number of airports decision support database service offers a valuable collection of tables that provide historic and forecast data.

Decision Support Database – Number of Commercial Aircraft In Service

Decision Support Database

Table — Number of Commercial Aircrafts in Service

Region / Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	CAGR % (2007 - 2014)
North America												
Canada	29,614.0	30,244.0	31,018.0	31,886.0	32,758.0	33,641.0	34,570.0	35,564.0	36,620.0	37,745.0	38,909.0	2.88
United States	219,319.0	224,262.0	221,942.0	225,007.0	228,155.0	231,225.0	234,550.0	238,075.0	241,625.0	245,090.0	248,670.0	1.44
TOTAL	**248,933.0**	**254,506.0**	**252,960.0**	**256,893.0**	**260,913.0**	**264,866.0**	**269,120.0**	**273,639.0**	**278,245.0**	**282,835.0**	**287,579.0**	**1.63**
Latin America												
Argentina	4,224.0	4,253.0	4,288.0	4,330.0	4,379.0	4,435.0	4,496.0	4,562.0	4,635.0	4,714.0	4,799.0	1.48
Brazil	10,831.0	10,995.0	11,113.0	11,351.0	11,632.0	11,918.0	12,223.0	12,547.0	12,885.0	13,249.0	13,631.0	2.65
Chile	70.0	71.0	71.0	72.0	73.0	74.0	74.0	75.0	75.0	76.0	77.0	0.96
Mexico	1,398.0	1,406.0	1,489.0	1,570.0	1,647.0	1,718.0	1,785.0	1,848.0	1,908.0	1,963.0	2,011.0	3.60
Peru	43.0	43.0	44.0	45.0	45.0	46.0	47.0	47.0	48.0	48.0	48.0	0.93
Venezuela	69.0	69.0	70.0	70.0	71.0	72.0	72.0	73.0	74.0	74.0	74.0	0.80
TOTAL	**16,635.0**	**16,837.0**	**17,075.0**	**17,438.0**	**17,847.0**	**18,263.0**	**18,697.0**	**19,152.0**	**19,625.0**	**20,124.0**	**20,640.0**	**2.44**
Asia - Pacific												
Australia	12,273.0	12,536.0	12,473.0	12,575.0	12,699.0	12,834.0	12,983.0	13,141.0	13,307.0	13,488.0	13,686.0	1.22
China	1,280.0	1,386.0	1,614.0	1,815.0	1,994.0	2,138.0	2,252.0	2,357.0	2,491.0	2,560.0	2,645.0	5.53
Hong Kong	171.0	188.0	209.0	228.0	245.0	261.0	275.0	287.0	298.0	308.0	316.0	4.77
India	1,058.0	1,077.0	1,099.0	1,123.0	1,148.0	1,175.0	1,204.0	1,235.0	1,268.0	1,302.0	1,338.0	2.53
Indonesia	237.0	240.0	244.0	248.0	252.0	256.0	261.0	266.0	271.0	276.0	282.0	1.85
Japan	2,675.0	2,658.0	2,665.0	2,680.0	2,702.0	2,728.0	2,757.0	2,791.0	2,829.0	2,869.0	2,913.0	1.20
Malaysia	122.0	122.0	123.0	124.0	124.0	125.0	126.0	127.0	127.0	128.0	129.0	0.57
New Zealand	57.0	57.0	58.0	58.0	59.0	60.0	61.0	61.0	62.0	63.0	63.0	1.19
Philippines	77.0	78.0	78.0	79.0	80.0	80.0	81.0	81.0	82.0	83.0	83.0	0.71
Singapore	160.0	160.0	161.0	163.0	165.0	168.0	171.0	175.0	180.0	185.0	191.0	2.29
South Korea	293.0	296.0	300.0	304.0	309.0	315.0	321.0	328.0	336.0	344.0	353.0	2.16
Taiwan	162.0	165.0	169.0	173.0	178.0	183.0	189.0	196.0	203.0	210.0	218.0	3.36
Thailand	120.0	121.0	123.0	125.0	128.0	131.0	132.0	133.0	135.0	137.0	138.0	1.42
TOTAL	**18,685.0**	**19,084.0**	**19,316.0**	**19,695.0**	**20,083.0**	**20,454.0**	**20,813.0**	**21,178.0**	**21,589.0**	**21,953.0**	**22,355.0**	**1.83**
Western Europe												
Austria	211.0	211.0	266.0	300.0	327.0	349.0	367.0	382.0	395.0	407.0	417.0	4.82
Belgium	126.0	126.0	159.0	181.0	196.0	208.0	218.0	227.0	234.0	240.0	244.0	4.36
Denmark	1,055.0	1,073.0	1,039.0	1,058.0	1,077.0	1,098.0	1,120.0	1,144.0	1,169.0	1,196.0	1,225.0	2.12
Finland	1,324.0	1,351.0	1,348.0	1,353.0	1,359.0	1,366.0	1,375.0	1,385.0	1,397.0	1,470.0	1,485.0	1.34
France	550.0	550.0	590.0	628.0	663.0	694.0	722.0	747.0	769.0	788.0	806.0	3.63
Germany	19,956.0	20,080.0	20,214.0	20,353.0	20,511.0	20,686.0	20,868.0	21,072.0	21,298.0	21,546.0	21,807.0	0.99
Greece	75.0	75.0	96.0	108.0	118.0	125.0	131.0	136.0	140.0	144.0	147.0	4.50
Iceland	376.0	393.0	397.0	407.0	405.0	409.0	414.0	419.0	425.0	432.0	439.0	1.09
Ireland	791.0	877.0	981.0	1,132.0	1,237.0	1,319.0	1,376.0	1,431.0	1,480.0	1,522.0	1,562.0	4.71
Italy	441.0	441.0	467.0	492.0	516.0	540.0	563.0	585.0	606.0	627.0	647.0	3.99
Luxembourg	62.0	62.0	83.0	85.0	87.0	90.0	94.0	98.0	102.0	107.0	112.0	4.02
Netherlands	154.0	154.0	246.0	249.0	252.0	256.0	261.0	266.0	271.0	277.0	283.0	1.85
Norway	22.0	22.0	23.0	23.0	24.0	25.0	26.0	26.0	26.0	27.0	28.0	2.85
Portugal	90.0	177.0	218.0	253.0	281.0	303.0	322.0	340.0	356.0	369.0	381.0	6.02
Spain	486.0	486.0	578.0	644.0	701.0	750.0	792.0	829.0	861.0	889.0	914.0	5.13
Sweden	2,596.0	2,611.0	2,614.0	2,533.0	2,541.0	2,552.0	2,567.0	2,583.0	2,601.0	2,623.0	2,647.0	0.63
Switzerland	3,893.0	3,841.0	3,822.0	3,813.0	3,804.0	3,794.0	3,782.0	3,768.0	3,754.0	3,737.0	3,718.0	(0.36)
United Kingdom	17,013.0	17,588.0	17,894.0	18,445.0	19,890.0	21,164.0	22,150.0	23,084.0	23,926.0	24,706.0	25,460.0	4.71
TOTAL	**49,221.0**	**50,118.0**	**51,035.0**	**52,057.0**	**53,989.0**	**55,728.0**	**57,148.0**	**58,522.0**	**59,810.0**	**61,107.0**	**62,322.0**	**2.60**
Eastern Europe												
Czech Republic	785.0	814.0	842.0	875.0	906.0	934.0	959.0	983.0	1,005.0	1,023.0	1,042.0	2.53
Hungary	40.0	57.0	69.0	80.0	88.0	94.0	99.0	103.0	107.0	110.0	113.0	5.06
Poland	1,100.0	1,122.0	1,151.0	1,161.0	1,172.0	1,185.0	1,199.0	1,215.0	1,233.0	1,252.0	1,272.0	1.31
Russia	-	-	-	-	-	-	-	-	-	-	-	-
Turkey	202.0	240.0	259.0	250.0	266.0	280.0	293.0	305.0	316.0	326.0	335.0	4.27
TOTAL	**2,127.0**	**2,233.0**	**2,321.0**	**2,366.0**	**2,432.0**	**2,493.0**	**2,550.0**	**2,606.0**	**2,661.0**	**2,711.0**	**2,762.0**	**2.24**
Middle East & Africa												
Egypt	55.0	56.0	57.0	57.0	59.0	60.0	60.0	61.0	62.0	64.0	65.0	1.89
Israel	52.0	53.0	53.0	53.0	53.0	54.0	56.0	57.0	58.0	58.0	61.0	2.03
Saudi Arabia	200.0	204.0	209.0	215.0	221.0	227.0	234.0	241.0	249.0	258.0	268.0	3.20
South Africa	8,822.0	9,314.0	9,713.0	10,088.0	10,442.0	10,766.0	11,064.0	11,331.0	11,576.0	11,813.0	12,028.0	2.54
TOTAL	**9,129.0**	**9,627.0**	**10,032.0**	**10,413.0**	**10,775.0**	**11,107.0**	**11,414.0**	**11,690.0**	**11,945.0**	**12,193.0**	**12,422.0**	**2.55**
WORLD TOTAL	**344,730.0**	**352,405.0**	**352,739.0**	**358,862.0**	**366,039.0**	**372,911.0**	**379,742.0**	**386,787.0**	**393,875.0**	**400,923.0**	**408,080.0**	**1.85**

Note: All figures are rounded; the base year is 2007. Source: Frost & Sullivan

Definition

Number of commercial aircrafts in service means the total number of carriers performing scheduled or non-scheduled air transport services or both available to the public for the carriage of passengers, mail or cargo for remuneration.

Note

1. Hyphen indicates non availability of data

Frost & Sullivan's number of commercial aircraft in service decision support database service offers a valuable collection of tables that provide historic and forecast data.

Decision Support Database – Total NOx Emissions

Decision Support Database

Table: NOx Emissions - Total (Mn Tons)

Region / Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	CAGR % (2007 - 2014)
North America												
Canada	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	(0.30)
United States	17.7	17.0	16.1	15.4	14.9	14.4	13.9	13.5	13.1	12.8	12.5	(3.00)
TOTAL	**19.7**	**18.9**	**18.0**	**17.4**	**16.9**	**16.3**	**15.9**	**15.5**	**15.1**	**14.7**	**14.4**	**(2.67)**
Latin America												
Argentina	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9	2.0	2.0	2.1	3.50
Brazil	8.7	9.1	9.6	10.0	10.4	10.9	11.3	11.7	12.2	12.6	13.0	3.82
Chile	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	1.59
Mexico	2.4	2.5	2.5	2.6	2.6	2.7	2.7	2.8	2.9	3.0	3.0	2.50
Peru	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.08
Venezuela	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.8	3.00
TOTAL	**14.6**	**15.3**	**15.9**	**16.6**	**17.2**	**17.9**	**18.5**	**19.1**	**19.7**	**20.3**	**20.9**	**3.39**
Asia - Pacific												
Australia	2.5	2.3	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.3	2.3	(0.90)
China	12.5	12.6	12.6	12.7	13.0	13.4	13.8	14.2	14.7	15.1	15.6	3.03
Hong Kong	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	(0.60)
India	5.2	5.4	5.6	5.8	5.9	6.1	6.2	6.4	6.5	6.7	6.8	2.49
Indonesia	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.2	1.41
Japan	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.6	(2.01)
Malaysia	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	4.01
New Zealand	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.82
Philippines	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.45
Singapore	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.39
South Korea	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.6	1.6	1.50
Taiwan	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	(1.44)
Thailand	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	3.52
TOTAL	**28.1**	**28.2**	**28.8**	**29.1**	**29.6**	**30.2**	**30.8**	**31.4**	**32.1**	**32.7**	**33.4**	**2.02**
Western Europe												
Austria	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	(0.38)
Belgium	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	(2.26)
Denmark	0.9	1.1	1.4	1.6	1.7	1.8	2.0	2.1	2.3	2.4	2.5	6.96
Finland	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	(1.91)
France	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.1	(2.64)
Germany	1.6	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	(5.14)
Greece	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	(2.63)
Iceland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.46
Ireland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	(1.14)
Italy	1.2	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	(1.10)
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(0.86)
Netherlands	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	(3.92)
Norway	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	(5.59)
Portugal	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	(1.64)
Spain	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	(3.40)
Sweden	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	(3.51)
Switzerland	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	(2.96)
United Kingdom	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	(1.00)
TOTAL	**10.9**	**10.8**	**10.8**	**10.6**	**10.5**	**10.4**	**10.3**	**10.3**	**10.2**	**10.1**	**10.1**	**(0.81)**
Eastern Europe												
Czech Republic	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	(0.90)
Hungary	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.54
Poland	0.8	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	(0.36)
Russia	4.9	4.6	4.8	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.0	2.67
Turkey	1.0	1.0	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	(4.95)
TOTAL	**7.1**	**6.9**	**7.3**	**7.4**	**7.5**	**7.5**	**7.6**	**7.8**	**7.9**	**8.0**	**8.1**	**1.30**
Middle East & Africa												
Egypt	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.4	2.43
Israel	194.2	195.8	191.9	191.6	190.9	190.1	189.2	188.1	187.0	185.7	184.4	(0.55)
Saudi Arabia	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.5	2.24
South Africa	2.2	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.27
TOTAL	**198.6**	**200.4**	**196.7**	**196.5**	**196.0**	**195.4**	**194.6**	**193.6**	**192.6**	**191.4**	**190.2**	**(0.47)**
WORLD TOTAL	**279.0**	**280.6**	**277.4**	**277.6**	**277.7**	**277.8**	**277.8**	**277.6**	**277.5**	**277.3**	**277.0**	**(0.03)**

Note: All figures are rounded; the base year is 2007. Source: Frost & Sullivan

Definition

Total nitrogen oxide emissions is defined as the mass of the nitrogen oxides(NOx) released from the burning(combustion) of fuel and nitrogen in a particular country or region. Nitrogen oxides include the gases nitrogen oxide (NO) and nitrogen dioxide (NO2).

Note

1. Figures for 2007 are Frost & Sullivan Estimates.

Frost & Sullivan's total NOx emissions decision support database service offers a valuable collection of tables that provide historic and forecast data.

About Frost & Sullivan

Who is Frost & Sullivan

The Growth Consulting Company

- Founded in 1961, Frost & Sullivan has over **45 years** of assisting clients with their decision-making and growth issues.
- Over 1,700 Growth Consultants and Industry Analysts across 32 global locations
- Over 10,000 clients worldwide - emerging companies, the global 1000 and the investment community
- Developers of the **Growth Excellence Matrix** – industry leading growth positioning tool for corporate executives
- Developers of **T.E.A.M. Methodology**, proprietary process to ensure that clients receive a 360^o perspective of technology, markets and growth opportunities
- Three core services: **Growth Partnership Services**, **Growth Consulting** and **Career Best Practices**

What Makes Us Unique

- **Exclusively Focused on Growth**

  Global thought leader exclusively focused on addressing client growth strategies and plans--Team actively engaged in research and developing of growth models that enable clients to achieve aggressive growth objectives.

- **Industry Breadth**

  Cover the broad spectrum of industries and technologies to provide clients with the ability to look outside the box and discover new and innovative ideas.

- **Global Perspective**

  About 32 global offices ensure that clients receive a global coverage/perspective based on regional expertise.

- **360 Degree Perspective**

  Proprietary T.E.A.M. methodology integrates all six critical research methodologies to significantly enhance the accuracy of decision making and lower the risk of implementing growth strategies.

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  Continuously monitor changing technology, markets and economics, and proactively address clients growth initiatives and position.

- **Trusted Partner**

  Working closely with client Growth Teams--helping them generate new growth initiatives and leverage all of Frost & Sullivan assets to accelerate their growth.

T.E.A.M. Methodology

Frost & Sullivan's proprietary **T.E.A.M. methodology**, ensures that clients have complete "360 Degree Perspective" to drive decision-making. **T**echnical, **E**conometric, **A**pplication, and **M**arket information ensures that clients have a comprehensive view of industries, markets, and technology.

Technical	Real-time intelligence on technology, including emerging technologies, new R&D breakthroughs, technology forecasting, impact analysis, groundbreaking research, and licensing opportunities.
Econometric	In-depth qualitative and quantitative research focused on timely, critical, global, regional, and country specific trends, including the political, demographic, and socioeconomic landscapes.
Application	Insightful strategies, networking opportunities, and best practices that can be applied for enhanced market growth; interactions between the client, peers, and Frost & Sullivan representatives that result in added value and effectiveness.
Market	Global and regional market analysis, including drivers and restraints, market trends, regulatory changes, competitive insights, growth forecasts, industry challenges, strategic recommendations, and end-user perspectives.

Global Perspective

- Over 1700 staff across every major market worldwide.
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